

# Optoelectronică

Curs 2

2018/2019

# Disciplina 2018/2019

- ▶ 2C/1L Optoelectronică **OPTO**
- ▶ **Minim 7 prezente curs + laborator**
- ▶ Curs – conf. **Radu Damian**
  - an IV  $\mu E$
  - Vineri 8-11, P5
  - E – 70% din nota
    - **20% test la curs**, saptamana 4-5?
  - probleme + (? 1 subiect teorie) + (2p prez. curs)
  - toate materialele permise
- ▶ Laborator – **sl. Daniel Matasaru**
  - an IV  $\mu E$ 
    - Marti 14-16
    - Joi 8-12 par/impar
  - L – 30% din nota (+Caiet de laborator)

# Orar 2018/2019

## ▶ Curs

- Vineri 8–11, P5
- **2C ⇒ 3C**
  - $14 * 2/3 \approx 9.33$
  - $9 \div 10$  C

# Scop 4



**Sinapse  
“ingineresti”**



# Bibliografie

- ▶ <http://rf-opto.etti.tuiasi.ro>
- ▶ Irinel Casian-Botez, "Structuri Optoelectronice", Ed. "CANOVA", Iasi 2001, ISBN 973-96099-2-9
- ▶ Behzad Razavi - Design of Integrated Circuits for Optical Communications, Mc Graw Hill  
~~<http://rf-opto.etti.tuiasi.ro/docs/opto/>~~
- ▶ IBM - Understanding Optical Communications: on-line <http://rf-opto.etti.tuiasi.ro>
- ▶ Radu Damian, I Casian, D Matăsaru - „Comunicatii Optice” , Indrumar de laborator, 2005

# Fotografii



## Date:

<b>Grupa</b>	5304 (2015/2016)
<b>Specializarea</b>	Tehnologii si sisteme de telecomunicatii
<b>Marca</b>	5184

[Trimite email acestui student](#) | [Adauga acest student la lista \(0\)](#)

## Detalii curente

<b>Finantare</b>	Buget
<b>Bursa</b>	Fara Bursa

## Observatii



## Date:

<b>Grupa</b>	5304 (2015/2016)
<b>Specializarea</b>	Tehnologii si sisteme de telecomunicatii
<b>Marca</b>	5184

[Acceseaza ca acest student](#)

## Note obtinute

Disciplina	Tip	Data	Descriere	Nota	Puncte	Obs.
<b>TW</b>	<b>Tehnologii Web</b>					
	N	17/01/2014	Nota finala	10	-	
	A	17/01/2014	Colocviu Tehnologii Web 2013/2014	10	7.55	
	B	17/01/2014	Laborator Tehnologii Web 2013/2014	9	-	
	D	17/01/2014	Tema Tehnologii Web 2013/2014	9	-	



## Date:

<b>Grupa</b>	5304 (2015/2016)
<b>Specializarea</b>	Tehnologii si sisteme de telecomunicatii
<b>Marca</b>	5244

[Trimite email acestui student](#) | [Adauga acest student la lista \(0\)](#)

## Detalii curente

<b>Finantare</b>	Buget
<b>Bursa</b>	Bursa de Studii

## Observatii

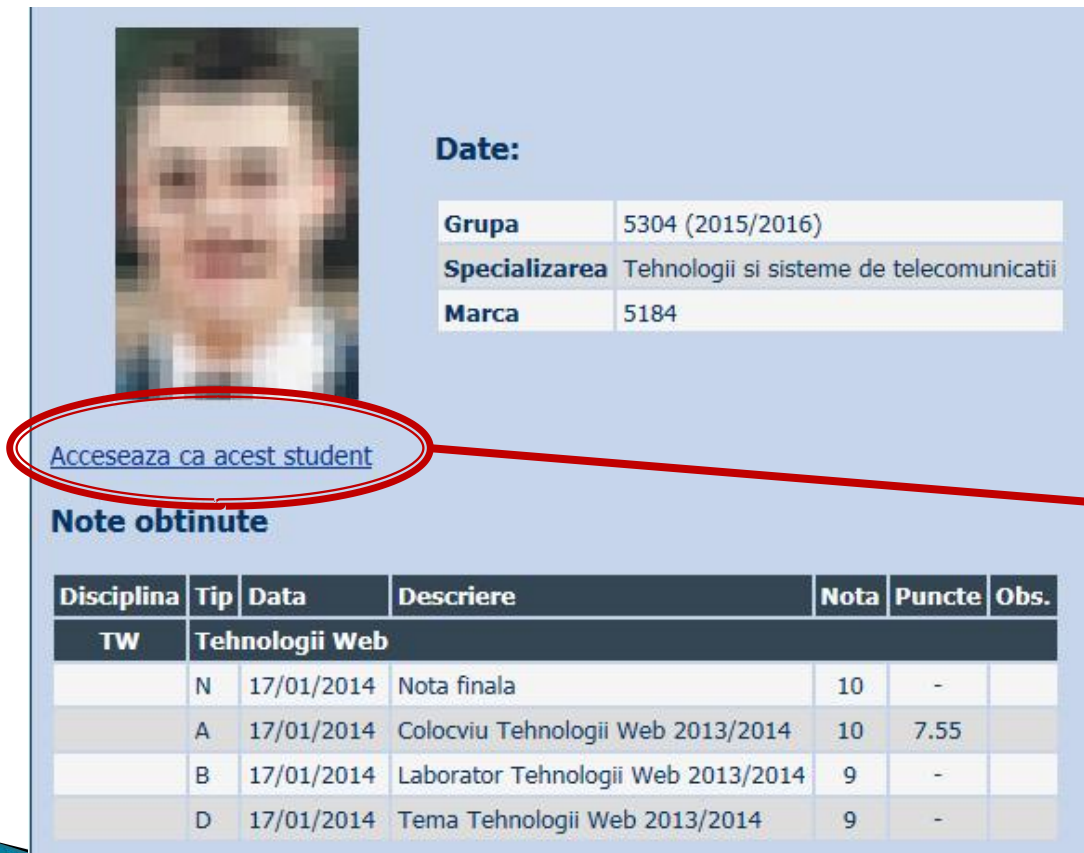
# Fotografii

Nr. Student	Prezent	Nr. Student	Prezent	Nr. Student	Prezent
1 ANGHIELUS IONUT-MARIUS	<input type="checkbox"/>	2 ANTIGHIN FLORIN-RAZVAN	<input type="checkbox"/>	3 ANTONICA BIANCA	<input type="checkbox"/>
4 APOSTOL PAVEL-MANUEL	<input type="checkbox"/>	5 BALASCA IULIAN-PETRU	<input checked="" type="checkbox"/>	6 BOSTAN ANDREI-PETRICIA	<input type="checkbox"/>
7 BOTEZAT EMANUEL	<input type="checkbox"/>	8 BUTUNOI GEORGE-MADALIN	<input type="checkbox"/>	9 CHILEA SALUCA-MARIA	<input type="checkbox"/>
10 CHERITOIU ECATERINA	<input type="checkbox"/>	11 COJOC MARIUS	<input checked="" type="checkbox"/>	12 COJOCARI AURA-FLORINA	<input type="checkbox"/>

Nr. Student	Prezent
2 <u>ANTIGHIN FLORIN-RAZVAN</u>	<input type="checkbox"/> Puncte: 0 Nota: 0 Obs:

# Acces

## ▶ Personalizat



Student profile card showing a blurred photo, a 'Date:' section with a table, and a 'Note obtinute' table. A red oval highlights the link 'Acceseaza ca acest student'.

**Date:**

Grupa	5304 (2015/2016)
Specializarea	Tehnologii si sisteme de telecomunicatii
Marca	5184

[Acceseaza ca acest student](#)

**Note obtinute**

Disciplina	Tip	Data	Descriere	Nota	Puncte	Obs.
TW	Tehnologii Web					
N		17/01/2014	Nota finala	10	-	
A		17/01/2014	Colocviu Tehnologii Web 2013/2014	10	7.55	
B		17/01/2014	Laborator Tehnologii Web 2013/2014	9	-	
D		17/01/2014	Tema Tehnologii Web 2013/2014	9	-	



Login form with fields for Name, Email, and Verification Code. A red oval highlights the Email field, and another red oval highlights the Verification Code field. A red arrow points from the 'Acceseaza ca acest student' link to the Email field. A verification code '344bd9f' is displayed below the code field, and a 'Trimite' button is at the bottom.

Nume

Email

Cod de verificare

344bd9f

Trimite



# Examen

- ▶ subiecte **individuale**

# Reprezentare logaritmică

$$\text{dB} = 10 \cdot \log_{10} (P_2 / P_1)$$

$$\text{dBm} = 10 \cdot \log_{10} (P / 1 \text{ mW})$$

$$0 \text{ dB} = 1$$

$$+ 0.1 \text{ dB} = 1.023 (+2.3\%)$$

$$+ 3 \text{ dB} = 2$$

$$+ 5 \text{ dB} = 3$$

$$+ 10 \text{ dB} = 10$$

$$-3 \text{ dB} = 0.5$$

$$-10 \text{ dB} = 0.1$$

$$-20 \text{ dB} = 0.01$$

$$-30 \text{ dB} = 0.001$$

$$0 \text{ dBm} = 1 \text{ mW}$$

$$3 \text{ dBm} = 2 \text{ mW}$$

$$5 \text{ dBm} = 3 \text{ mW}$$

$$10 \text{ dBm} = 10 \text{ mW}$$

$$20 \text{ dBm} = 100 \text{ mW}$$

$$-3 \text{ dBm} = 0.5 \text{ mW}$$

$$-10 \text{ dBm} = 100 \mu\text{W}$$

$$-30 \text{ dBm} = 1 \mu\text{W}$$

$$-60 \text{ dBm} = 1 \text{ nW}$$

$$[\text{dBm}] + [\text{dB}] = [\text{dBm}]$$

$$[\text{dBm/Hz}] + [\text{dB}] = [\text{dBm/Hz}]$$

$$[\text{x}] + [\text{dB}] = [\text{x}]$$

# Calculul atenuarii

$$\text{Pierderi} = \frac{P_{out}}{P_{in}}$$

$$\text{Pierderi [dB]} = [-] 10 \cdot \log_{10} \left( \frac{P_{out}}{P_{in}} \right)$$

$$\text{Pierderi [dB]} = [-] (P_{out} [\text{dBm}] - P_{in} [\text{dBm}])$$



=



-



$$\text{Atenuare [dB/km]} = \frac{\text{Pierderi [dB]}}{\text{lungime [km]}}$$

# Recapitulare

# Introducere

## Capitolul 1

# Aplicatii majore

- ▶ Comunicatii

- Infrarosu (InGaAsP)

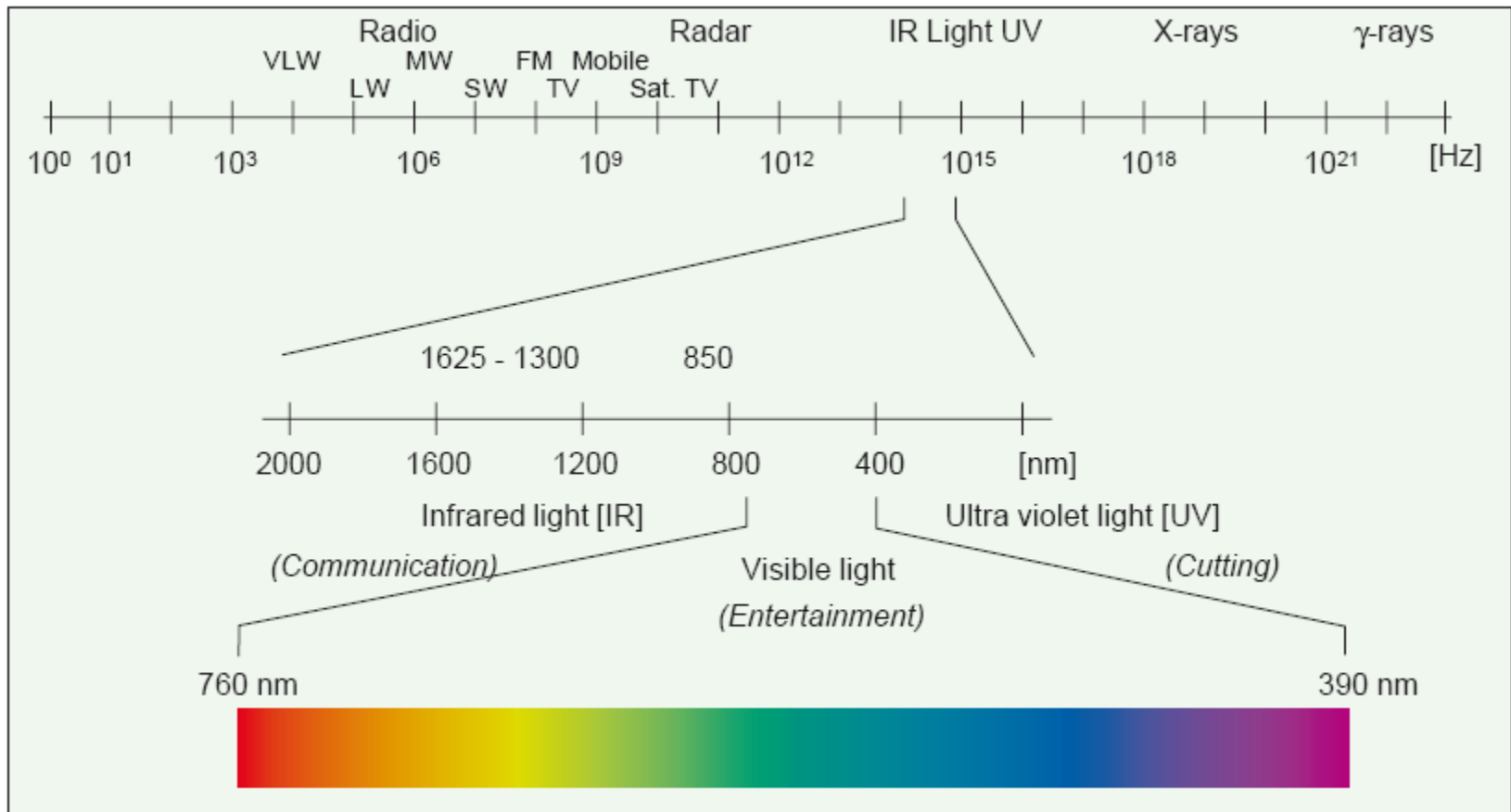
- ▶ Vizibil

- Spectru vizibil (GaAlAs)

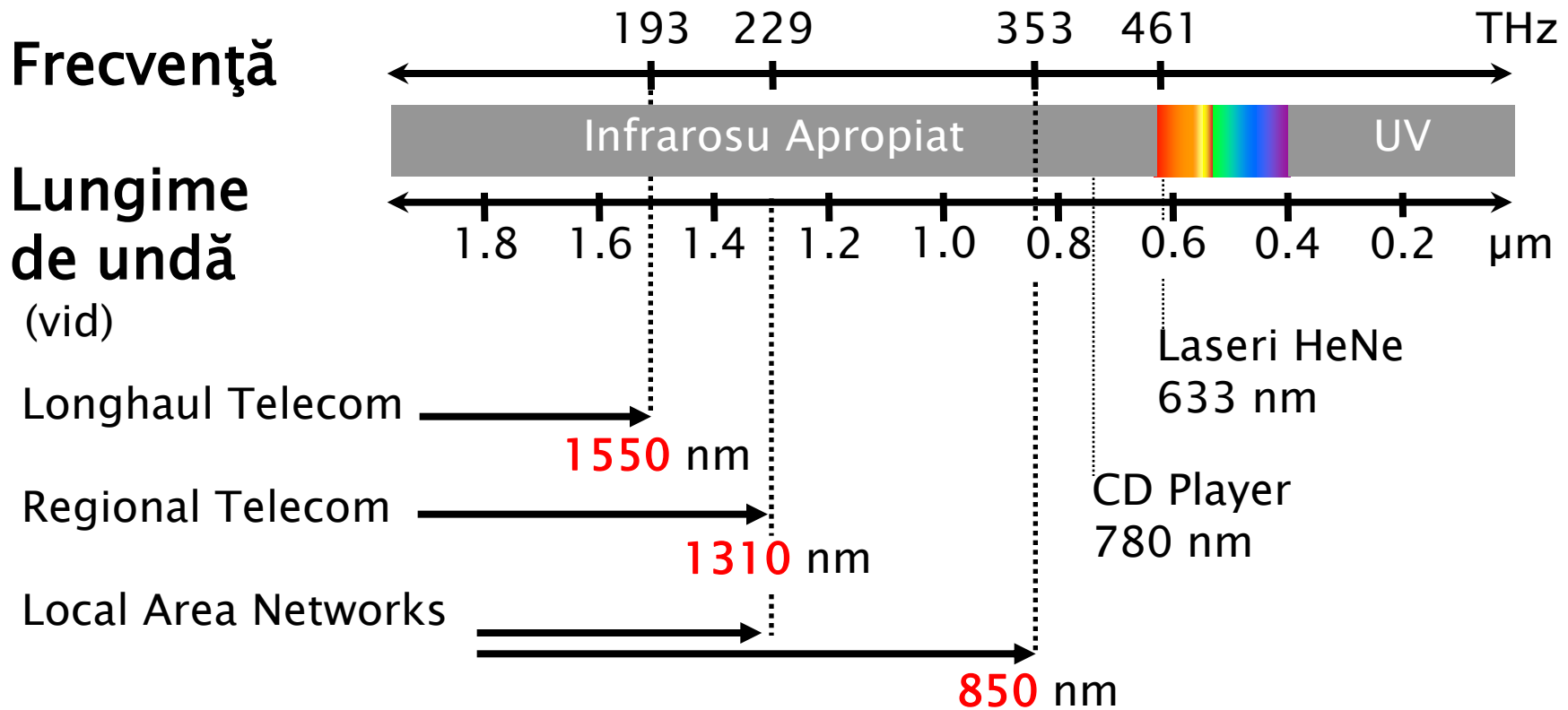
- ▶ Iluminare

- Putere ridicata, lumina alba (GaInN)

# Spectrul electromagnetic

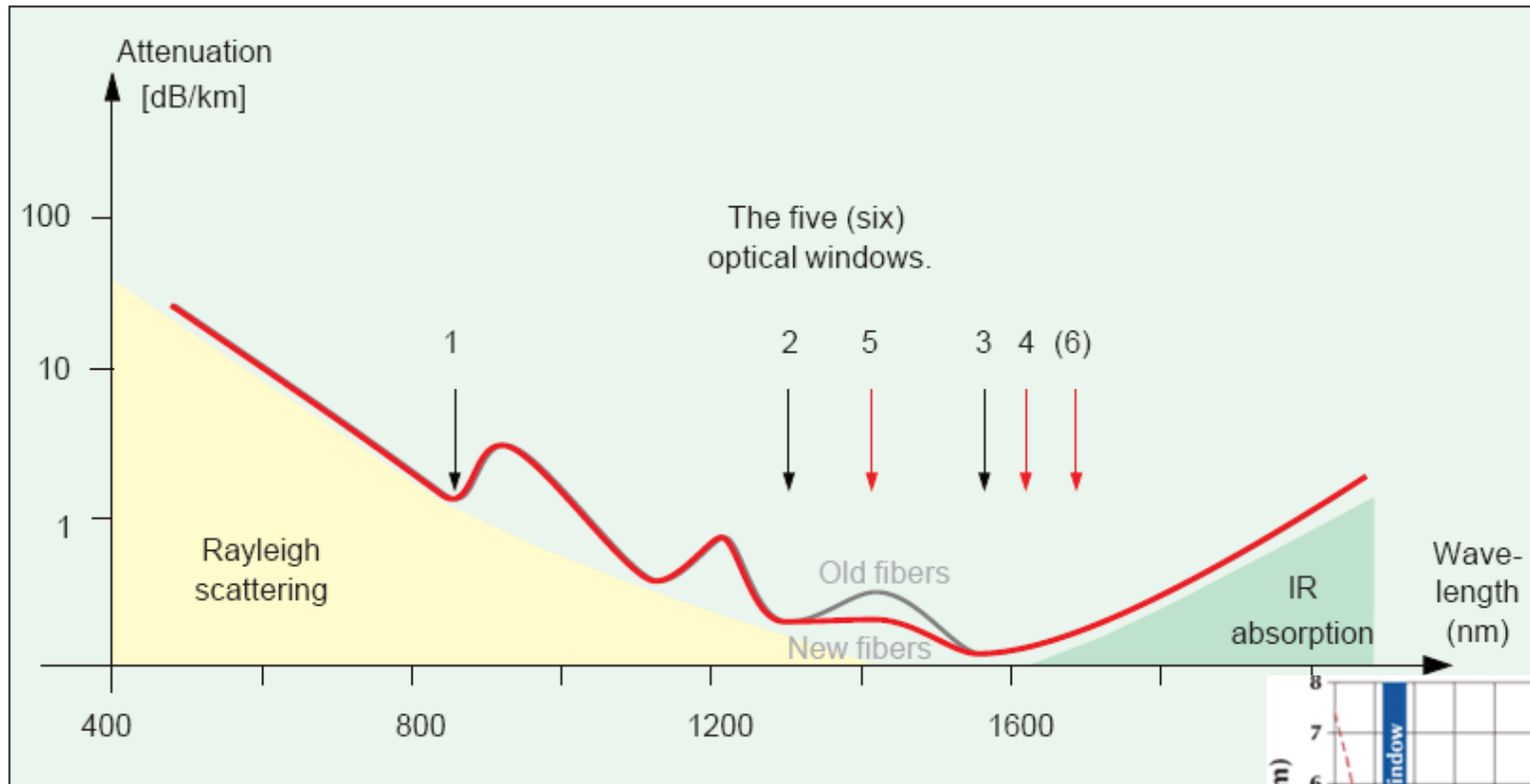


# Benzi de lucru in comunicațiile optice

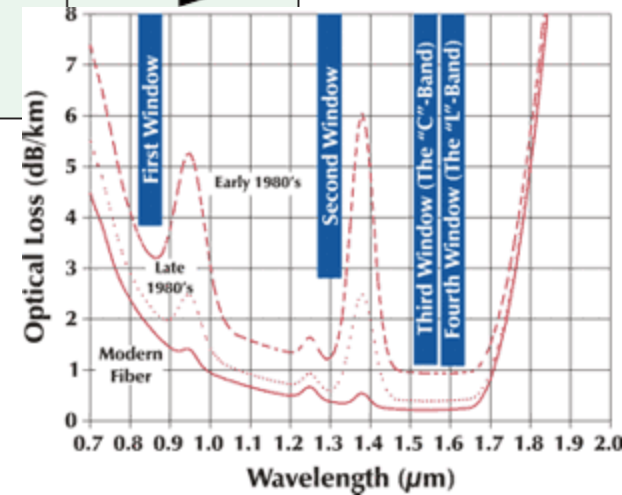




# Atenuarea în fibra optică (SiO<sub>2</sub>)



**850nm, 1310nm, 1550nm**



# Aplicatii majore

- ▶ Comunicatii
  - Infrarosu (InGaAsP)
- ▶ Vizibil
  - Spectru vizibil (GaAlAs)
- ▶ Illuminare
  - Putere ridicata, lumina alba (GaN)

# Premiul Nobel, Fizica, 2014



The image is a graphic announcement for the Nobel Prize in Physics 2014. It features a blue background with a gold Nobel Prize medal icon in the top left. The text is in both Swedish and English. At the top, it says "Nobelpriset i fysik 2014" and "The Nobel Prize in Physics 2014". Below this, the Swedish text "Nobelpriset i fysik 2014" is prominently displayed. To the right is the logo of the Royal Swedish Academy of Sciences, "KUNGL. VETENSKAPSKAS AKADEMIEN". The center of the graphic features three portraits of the laureates: Isamu Akasaki, Hiroshi Amano, and Shuji Nakamura. Below each portrait is their name and affiliation. At the bottom, the award citation is written in Swedish and English. The date "2014-10-07" and the copyright "© Kungl. Vetenskapsakademien" are at the bottom.

Nobelpriset i fysik 2014

The Nobel Prize in Physics 2014

KUNGL. VETENSKAPSKAS AKADEMIEN  
THE ROYAL SWEDISH ACADEMY OF SCIENCES

**Isamu Akasaki**  
Meijo University, Nagoya, Japan  
Nagoya University, Japan

**Hiroshi Amano**  
Nagoya University, Japan

**Shuji Nakamura**  
University of California,  
Santa Barbara, CA, USA

*"För uppfinningen av effektiva blå lysdioder vilka möjliggjort ljusstarka och energisnåla vita ljuskällor"*

*"For the invention of efficient blue light-emitting diodes which has enabled bright and energy-saving white light sources"*

2014-10-07

© Kungl. Vetenskapsakademien

# Aplicatii majore

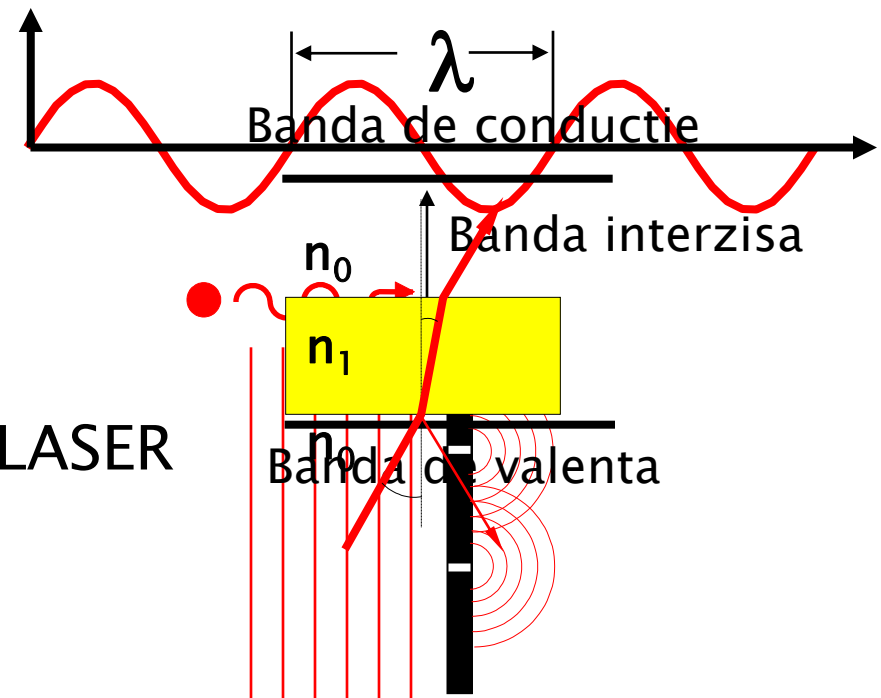
- ▶ Comunicatii
  - Infrarosu (InGaAsP)
- ▶ Vizibil
  - Spectru vizibil (GaAlAs)
- ▶ Iluminare
  - Putere ridicata, lumina alba (GaInN)

# Modelarea luminii

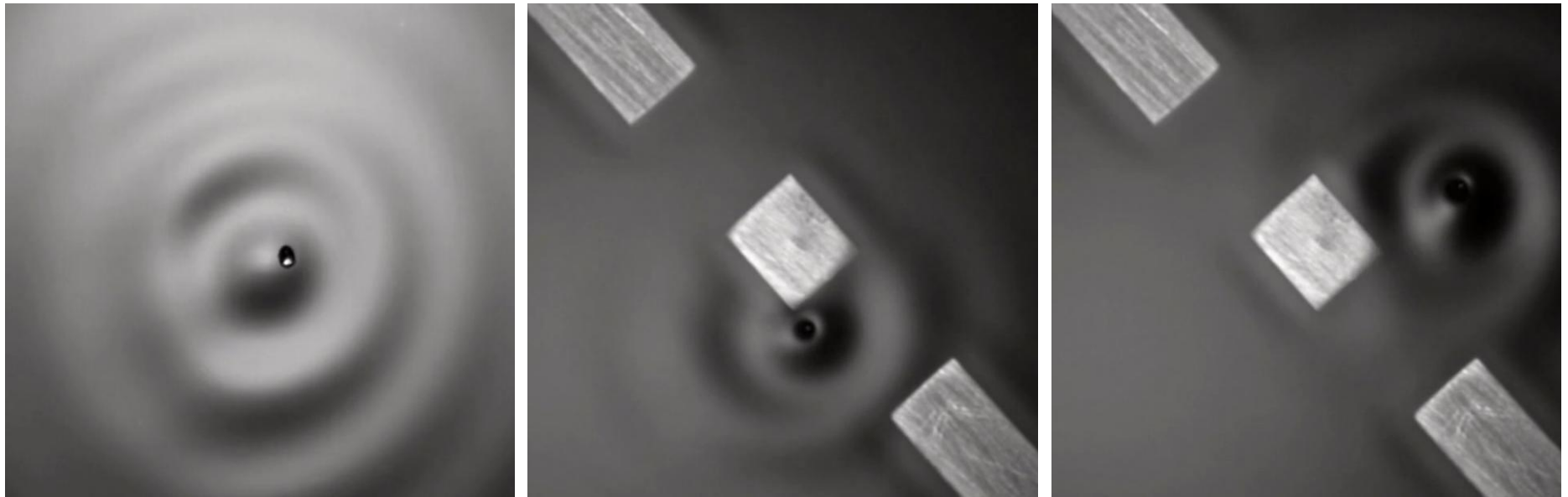
(tot) Capitolul 1

# Modelarea luminii

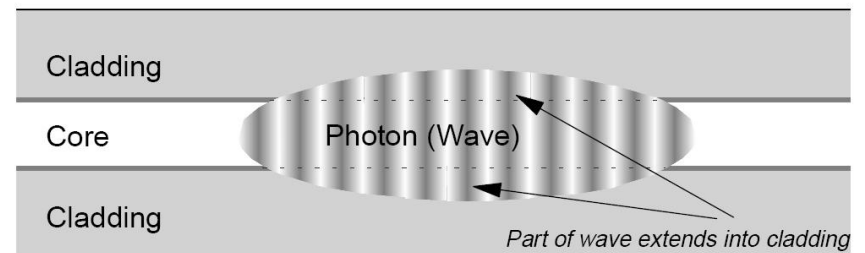
- ▶ Undă electromagnetică
  - Ecuațiile lui Maxwell
  - $\lambda$ ,  $\epsilon$ ,  $\omega$ ,  $f$
- ▶ Teoria cuantică
  - Benzi energetice  $E = h \nu$
  - fotoni, emisie stimulată, LASER
- ▶ Optică geometrică
  - $n$ ,  $\theta$
  - raze de lumină
  - intuitivă



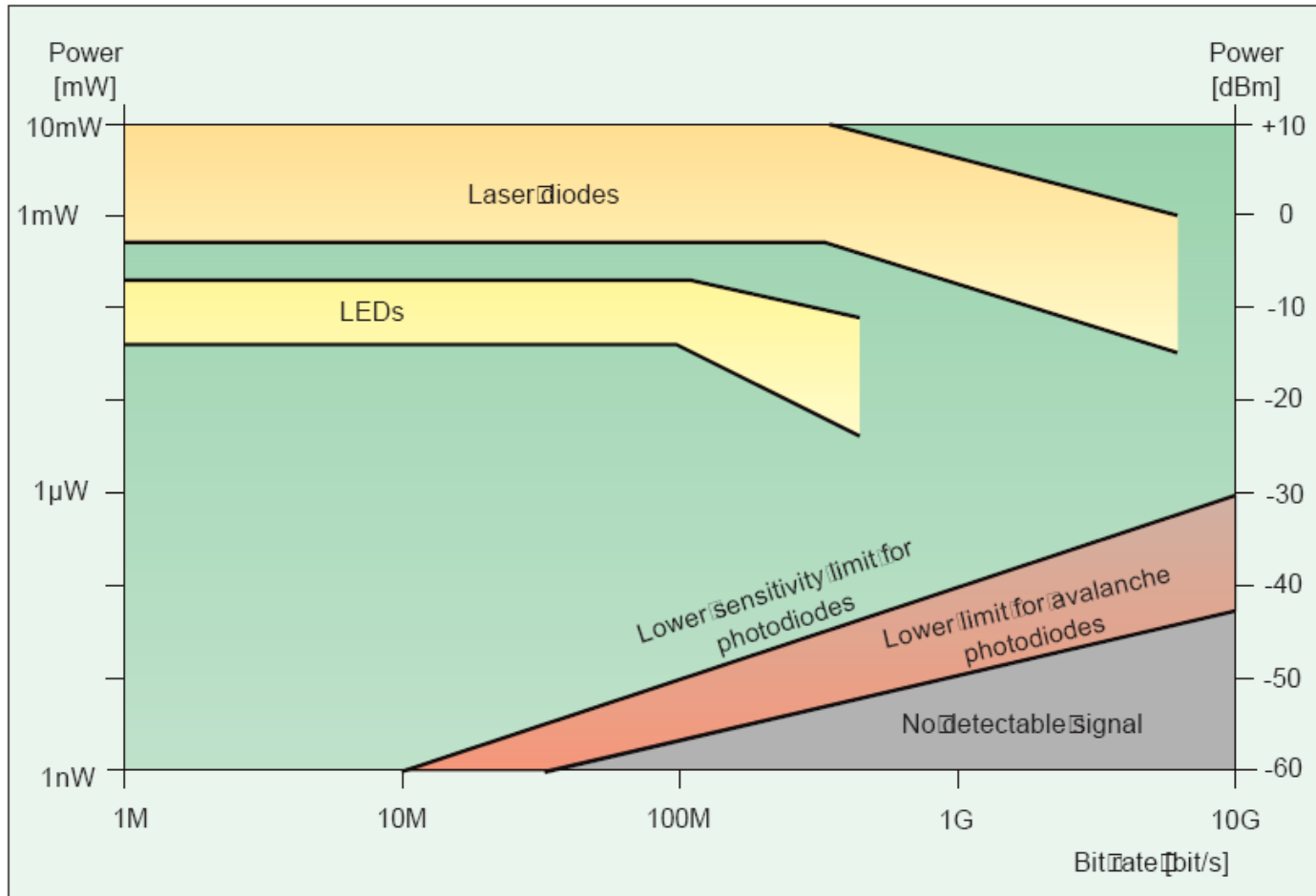
# Modelare



Through the Wormhole  
S02E07 How Does the Universe Work



# Limite putere/bandă a dispozitivelor optoelectronice





# Lumina ca undă electromagnetică

Capitolul 2

# Ecuatiile lui Maxwell

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

$$\nabla \times H = \frac{\partial D}{\partial t} + J$$

$$\nabla \cdot D = \rho$$

$$\nabla \cdot B = 0$$

$$\nabla \cdot J = -\frac{\partial \rho}{\partial t}$$

## ▶ Ecuatii constitutive

$$D = \varepsilon \cdot E$$

$$B = \mu \cdot H$$

$$J = \sigma \cdot E$$

## ▶ In vid

$$\mu_0 = 4\pi \times 10^{-7} \text{ H/m}$$

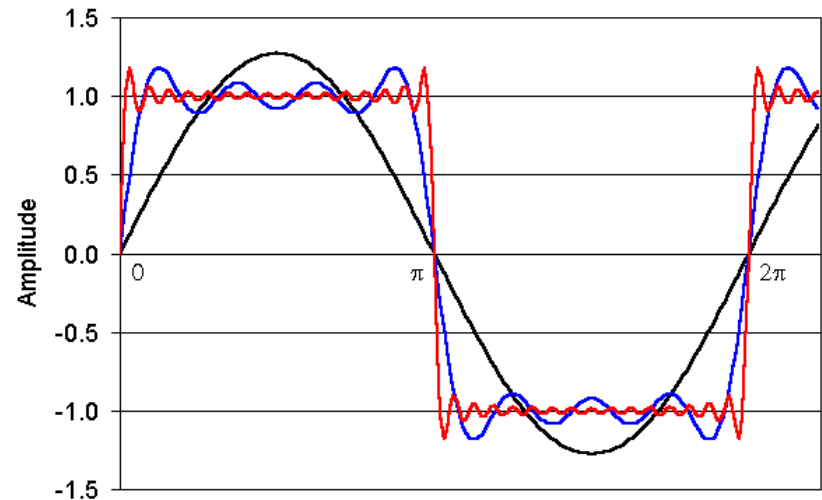
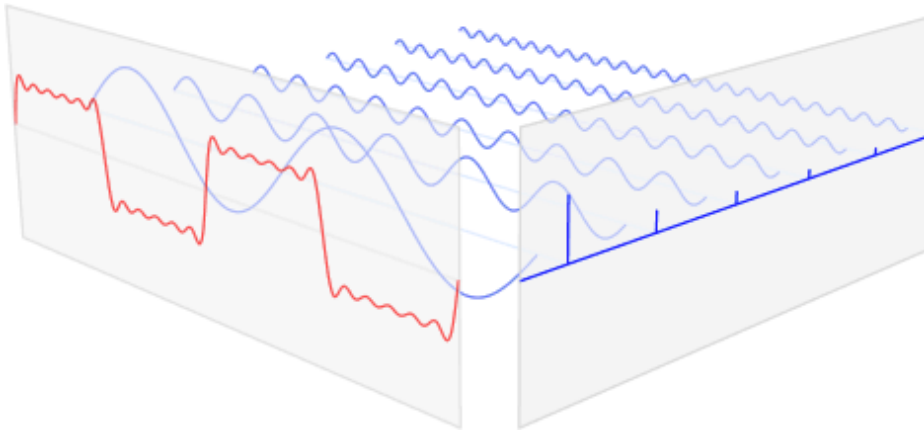
$$\varepsilon_0 = 8,854 \times 10^{-12} \text{ F/m}$$

$$c_0 = \frac{1}{\sqrt{\varepsilon_0 \cdot \mu_0}} = 2,99790 \cdot 10^8 \text{ m/s}$$

# Modele matematice

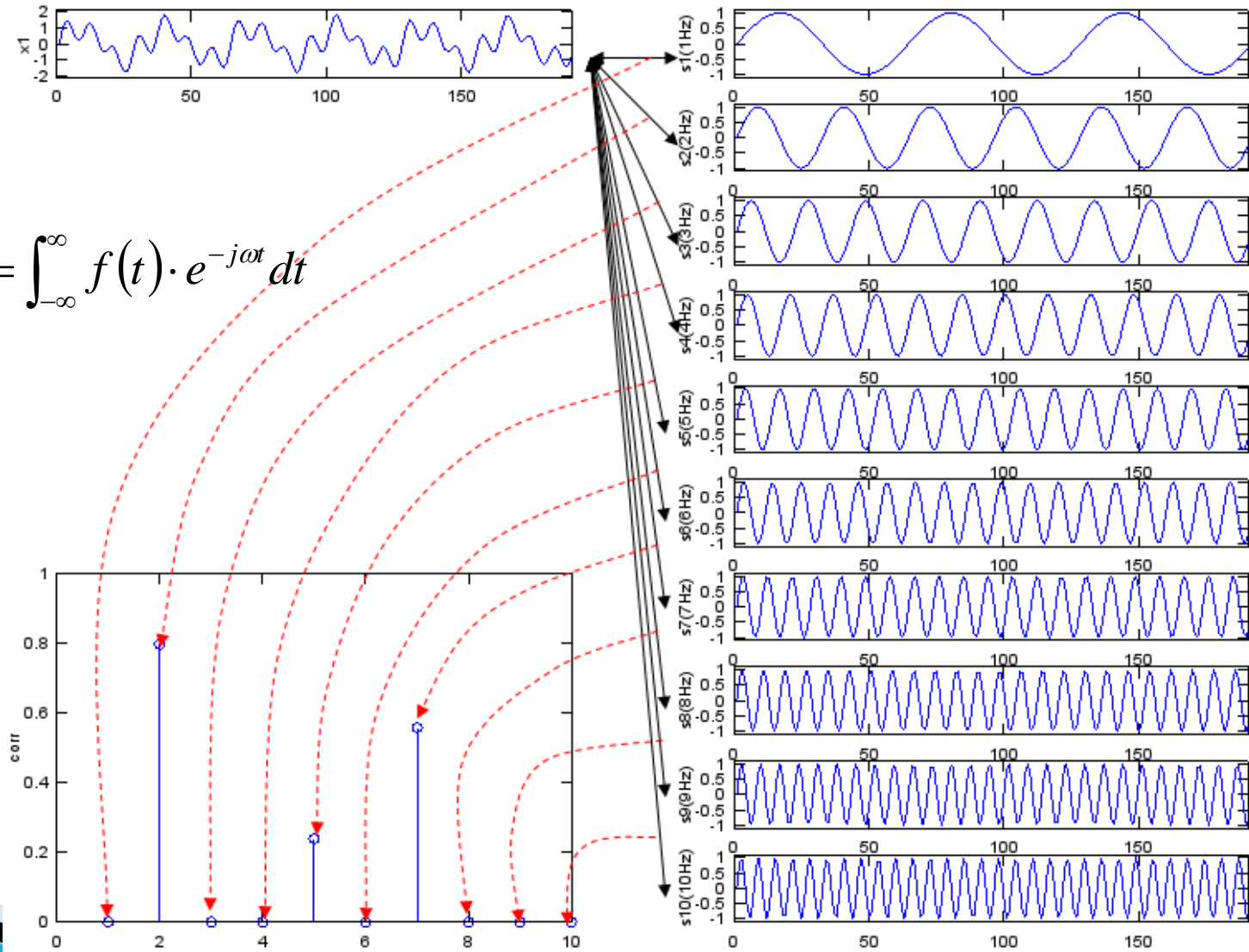
- ▶ cazuri particulare in care exista rezolvare analitica
  - semnale cu variație armonică în timp, transformata Fourier, spectru

$$X = X_0 e^{j \cdot \omega \cdot t} \quad \frac{\partial X}{\partial t} = j \cdot \omega \cdot X \quad g(\omega) = \int_{-\infty}^{\infty} f(t) \cdot e^{-j\omega t} dt \quad f(t) = \int_{-\infty}^{\infty} g(\omega) \cdot e^{j\omega t} d\omega$$

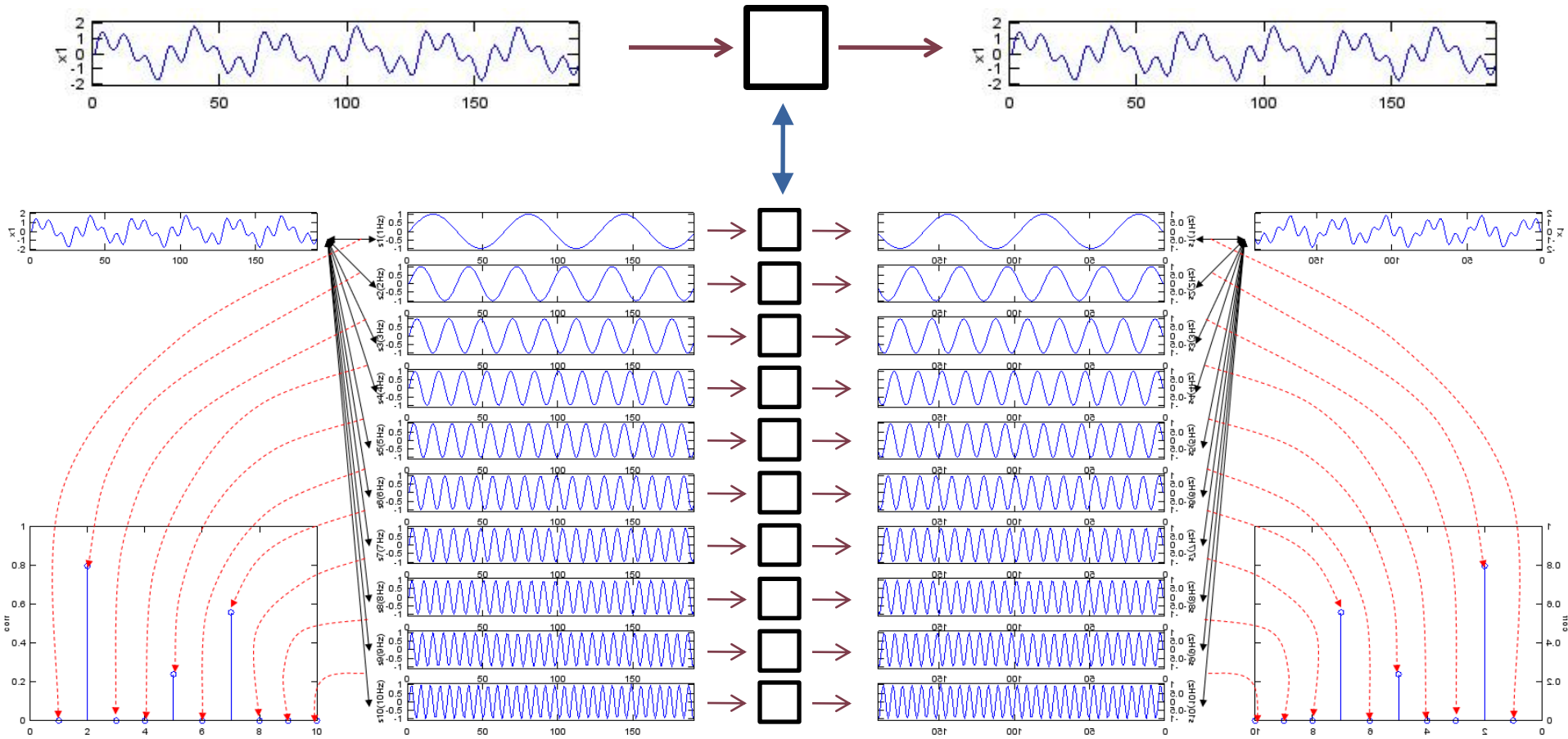


# Modelle matematiche

$$g(\omega) = \int_{-\infty}^{\infty} f(t) \cdot e^{-j\omega t} dt$$



# Modelle matematiche



$$F(\omega) = \int_{-\infty}^{\infty} f(t) \cdot e^{-j\omega t} dt$$

$$G(\omega)[F(\omega)]$$

$$g(t) = \int_{-\infty}^{\infty} G(\omega) \cdot e^{j\omega t} d\omega$$

# Câmpuri electromagnetice cu variație armonică în timp

$$X = X_0 e^{j \cdot \omega \cdot t} \quad \frac{\partial X}{\partial t} = j \cdot \omega \cdot X$$

## ▶ Simplificarea ecuațiilor lui Maxwell

$$\nabla^2 E + \omega^2 \epsilon \mu E = j \omega \mu J + \frac{1}{\epsilon} \nabla \rho$$

$$\nabla^2 H + \omega^2 \epsilon \mu H = -\nabla \times J$$

$$\nabla \cdot E = \frac{\rho}{\epsilon}$$

$$\nabla \cdot H = 0$$

## ▶ Ecuațiile Helmholtz sau ecuațiile de propagare

Mediu lipsit de sarcini electrice

$$\nabla^2 E - \gamma^2 E = 0$$

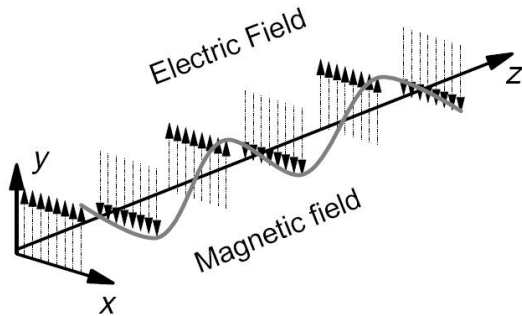
$$\nabla^2 H - \gamma^2 H = 0$$

$$\gamma^2 = -\omega^2 \epsilon \mu + j \omega \mu \sigma$$

$\gamma$  – Constanta de propagare

# Solutia ecuatiilor de propagare

Camp electric dupa directia Oy, ← prin alegerea judicioasa  
 propagare dupa directia Oz ← a sistemului de referinta



Propagare

$$E_y = E_+ e^{-\gamma \cdot z} + E_- e^{\gamma \cdot z}$$

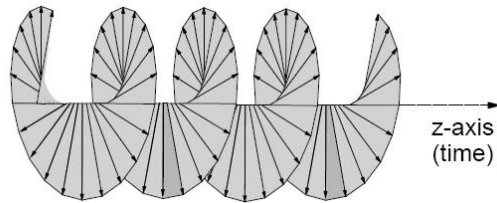
$$\gamma = \sqrt{-\omega^2 \epsilon \mu + j \omega \mu \sigma} = \alpha + j \cdot \beta$$

Exista numai unda progresiva  $E_+ \Rightarrow A$

$$E_y = A e^{-(\alpha + j \cdot \beta) \cdot z}$$

Camp armonic

$$E_y = A \cdot e^{-\alpha \cdot z} \cdot e^{j(\omega t - \beta \cdot z)}$$



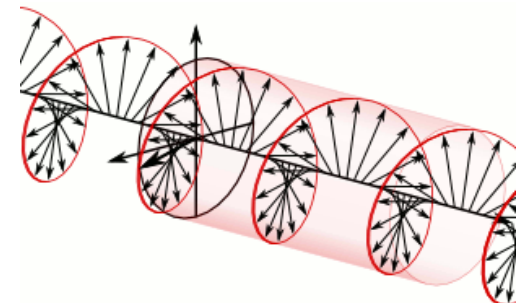
Polarizare circulara

Amplitudine

Atenuare

Propagare

(variatie in timp si spatiu)

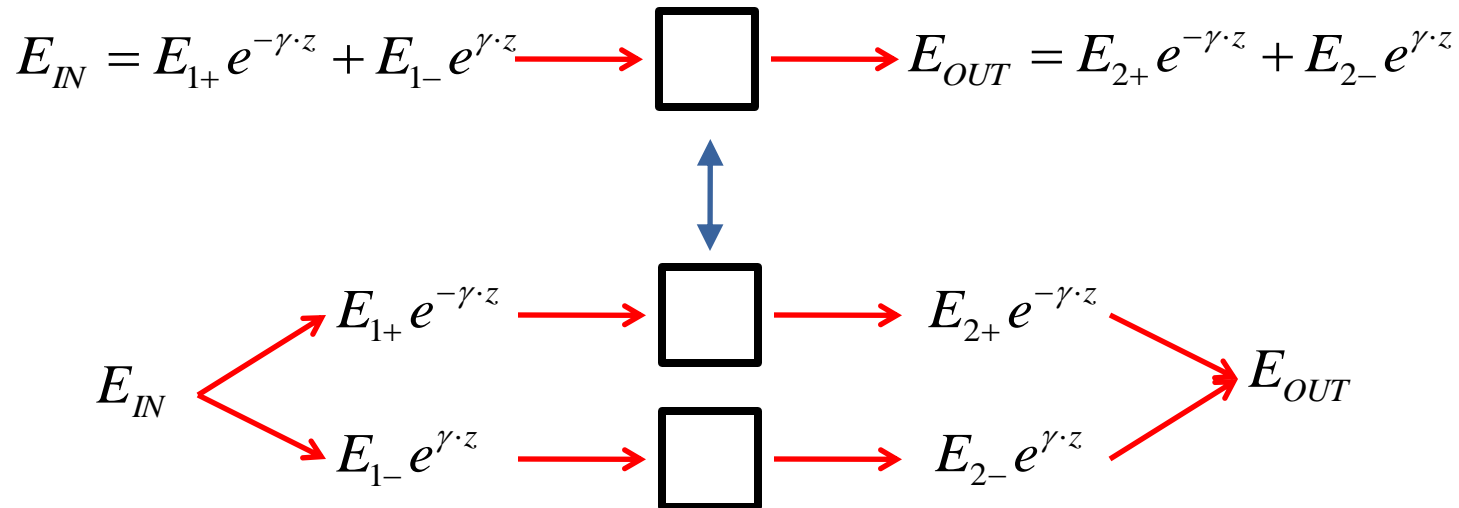


# Modele matematice

► cazuri particulare in care exista rezolvare analitica

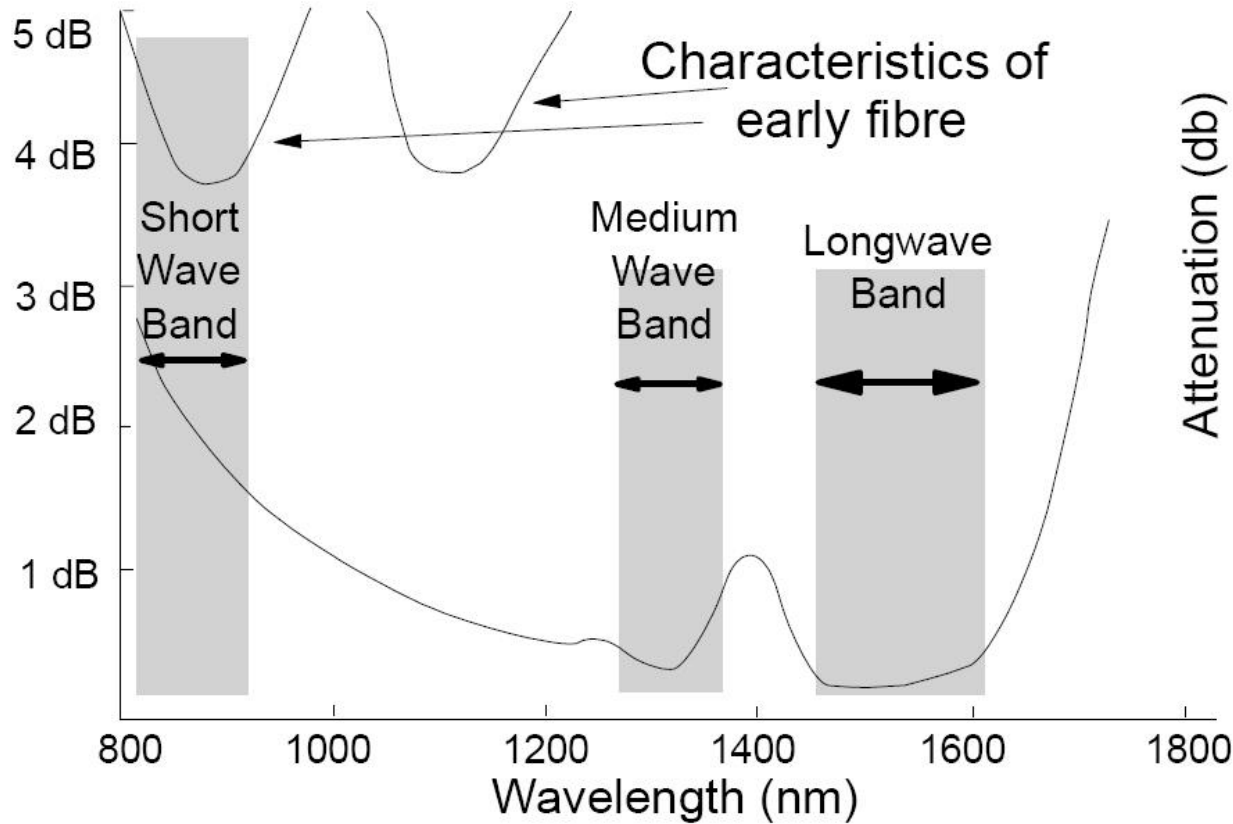
- unda
  - incidenta
  - reflectata
- unda
  - directa
  - inversa

$$E_y = E^+ \cdot e^{-\alpha \cdot z} \cdot e^{j(\omega t - \beta \cdot z)} + E^- \cdot e^{-\alpha \cdot z} \cdot e^{j(\omega t + \beta \cdot z)}$$





# Atenuarea pe 1 km in $\text{SiO}_2$



# Atenuare

$$E_y(z_1) = Ct \cdot e^{-\alpha \cdot z_1} \cdot e^{j(\omega t - \beta \cdot z_1)}$$

$$E_y(z_2) = Ct \cdot e^{-\alpha \cdot z_2} \cdot e^{j(\omega t - \beta \cdot z_2)}$$

$$W, P \sim \int E^2$$

$$A = \frac{P_2}{P_1} = \frac{Ct^2 \cdot e^{-2\alpha \cdot z_2}}{Ct^2 \cdot e^{-2\alpha \cdot z_1}} = e^{-2\alpha \cdot (z_2 - z_1)}$$

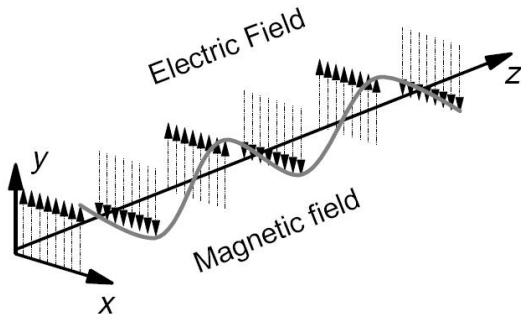
$$A[dB] = 10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \left[ e^{-2\alpha \cdot (z_2 - z_1)} \right]$$

$$A[dB] = -20 \cdot \alpha \cdot (z_2 - z_1) \log_{10} e = -8.686 \cdot \alpha \cdot (z_2 - z_1)$$

$$A / L [dB / km] = -8.686 \cdot \alpha < 0$$

- ▶ Atenuarea se exprima de obicei in **dB/km**
  - ▶ de obicei valori pozitive
  - ▶ semnul = **implicit**

# Parametri de propagare



$$\nabla \times E = -j\omega\mu \cdot H$$

$$H_x = \frac{j\gamma \cdot E_y}{\omega\mu}$$

Mediu fara pierderi,  $\sigma = 0$        $\gamma = j\omega \cdot \sqrt{\epsilon\mu}$

$$\eta = \frac{E_y}{H_x} = \sqrt{\frac{\mu}{\epsilon}} \quad \text{Impedanta intrinseca a mediului}$$

$E_y = A \cdot e^{-\alpha \cdot z} \cdot e^{j(\omega \cdot t - \beta \cdot z)}$       punctele de faza constanta:  $(\omega \cdot t - \beta \cdot z) = \text{const}$

Viteza de faza       $v = \frac{dz}{dt} = \frac{\omega}{\beta} = \frac{1}{\sqrt{\epsilon\mu}}$

Viteza de grup       $v_g = \frac{dz}{dt} = \frac{d\omega}{d\beta}$       in medii dispersive unde  $\beta = \beta(\omega)$

# Parametri de propagare

## ▶ In vid

$$\eta_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} = 377\Omega \quad v = v_g = c_0 \quad c_0 = \frac{1}{\sqrt{\varepsilon_0 \cdot \mu_0}} = 2,99790 \cdot 10^8 \text{ m/s}$$

$$\lambda_0 = \frac{2\pi}{\beta} = \frac{c_0}{f} \quad T = \frac{2\pi}{\omega} = \frac{1}{f}$$

Periodicitate in spatiu

Periodicitate in timp

## ▶ In mediu nedispersiv $\varepsilon_r$

$$c = \frac{1}{\sqrt{\varepsilon \cdot \mu_0}} = \frac{1}{\sqrt{\varepsilon_0 \varepsilon_r \cdot \mu_0}} = \frac{c_0}{\sqrt{\varepsilon_r}}$$

$$n = \sqrt{\varepsilon_r} \quad \text{Indice de refractie al mediului} \quad c = \frac{c_0}{n}$$

$$T = \frac{2\pi}{\omega} = \frac{1}{f}$$

$$\lambda = \frac{2\pi}{\beta} = \frac{c}{f}$$

$$\lambda = \frac{c_0}{n \cdot f} = \frac{\lambda_0}{n}$$



# Parametri, dependenta de mediu

$$\eta_0 = \sqrt{\frac{\mu_0}{\epsilon_0}} = 377\Omega$$

$$c_0 = \frac{1}{\sqrt{\epsilon_0 \cdot \mu_0}} = 2,99790 \cdot 10^8 \text{ m/s}$$

$n = 1$

$$T = \frac{2\pi}{\omega} = \frac{1}{f}$$

$$\lambda_0 = \frac{2\pi}{\beta} = \frac{c_0}{f}$$

$$\eta = \frac{\eta_0}{n}$$

$$c = \frac{c_0}{n}$$

$n = \sqrt{\epsilon_r}$

$$T = \frac{2\pi}{\omega} = \frac{1}{f}$$

$$\lambda = \frac{c_0}{n \cdot f} = \frac{\lambda_0}{n}$$

$$\lambda = \lambda(n)$$

$$f = \text{indep.}$$

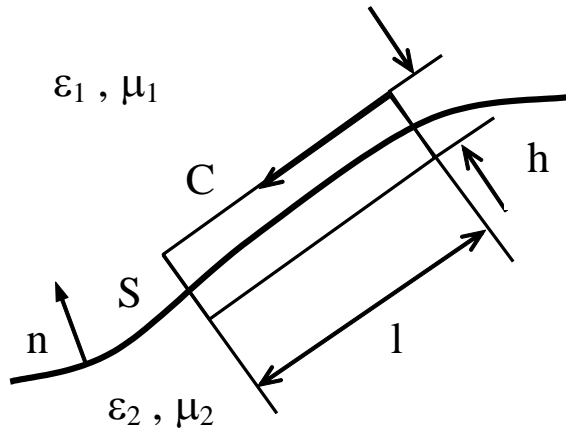
ITU G.692

"the allowed channel frequencies are based on a 50 GHz grid with the reference frequency at 193.10 THz"

SI

"a source that emits monochromatic radiation of frequency  $540 \cdot 10^{12}$  Hz"

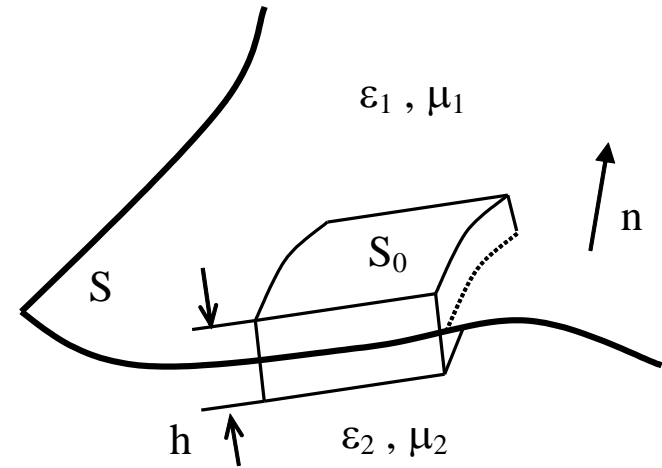
# Condiții la limita de separație între două medii



a)

$$n \times (E_1 - E_2) = 0$$

$$n \times (H_1 - H_2) = J_S$$



b)

$$n \cdot (D_1 - D_2) = \rho_S$$

$$n \cdot (B_1 - B_2) = 0$$

# Moduri in medii delimitate

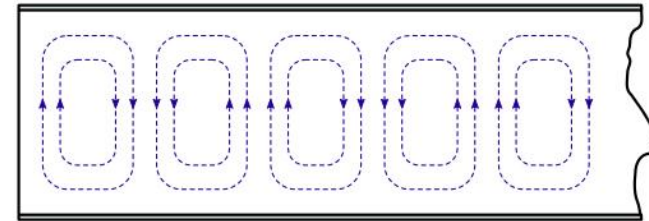
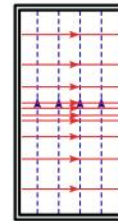
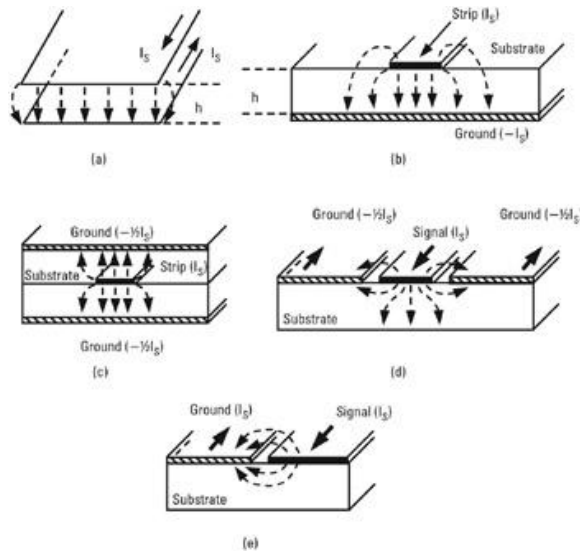
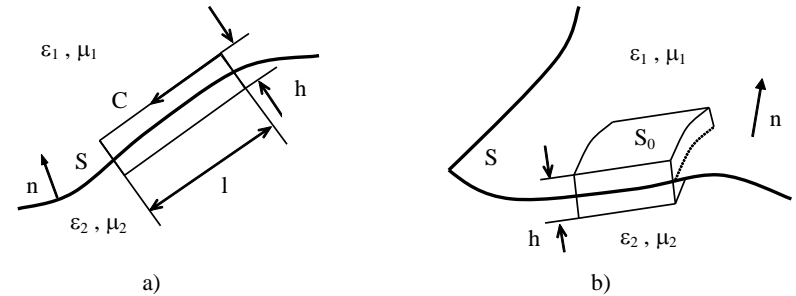
- ▶ Câmpuri electromagnetice cu variație armonică în timp
  - simplificarea ecuatiilor lui Maxwell

$$X = X_0 e^{j \cdot \omega \cdot t} \quad \frac{\partial X}{\partial t} = j \cdot \omega \cdot X \quad g(\omega) = \int_{-\infty}^{\infty} f(t) \cdot e^{-j\omega t} dt \quad f(t) = \int_{-\infty}^{\infty} g(\omega) \cdot e^{j\omega t} d\omega$$

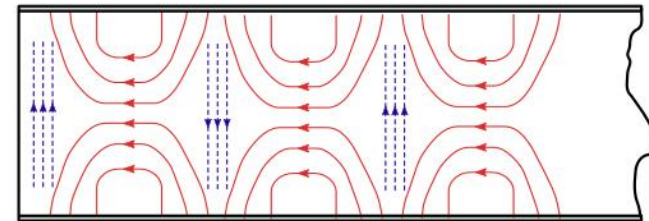
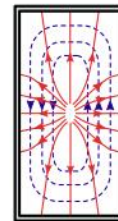
- ▶ In medii delimitate solutiile ecuatiilor lui Maxwell trebuie sa verifice conditiile la limita
  - solutiile trebuie sa respecte anumite conditii suplimentare

# Moduri in medii delimitate

- ▶ Câmpul electric trebuie sa fie perpendicular pe un perete metalic sau nul
- ▶ Câmpul magnetic trebuie sa fie tangent la un perete metalic sau nul



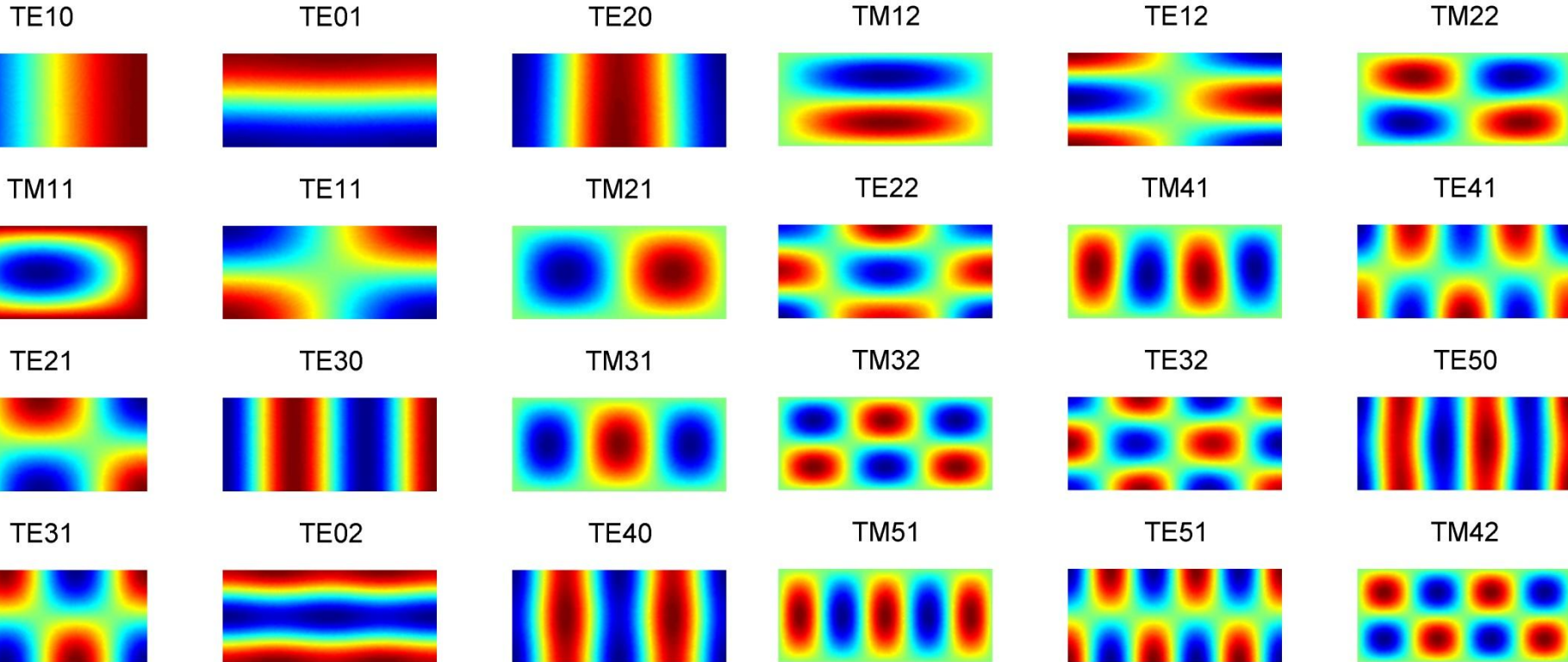
TE<sub>10</sub>



TM<sub>11</sub>



# Moduri in medii delimitate



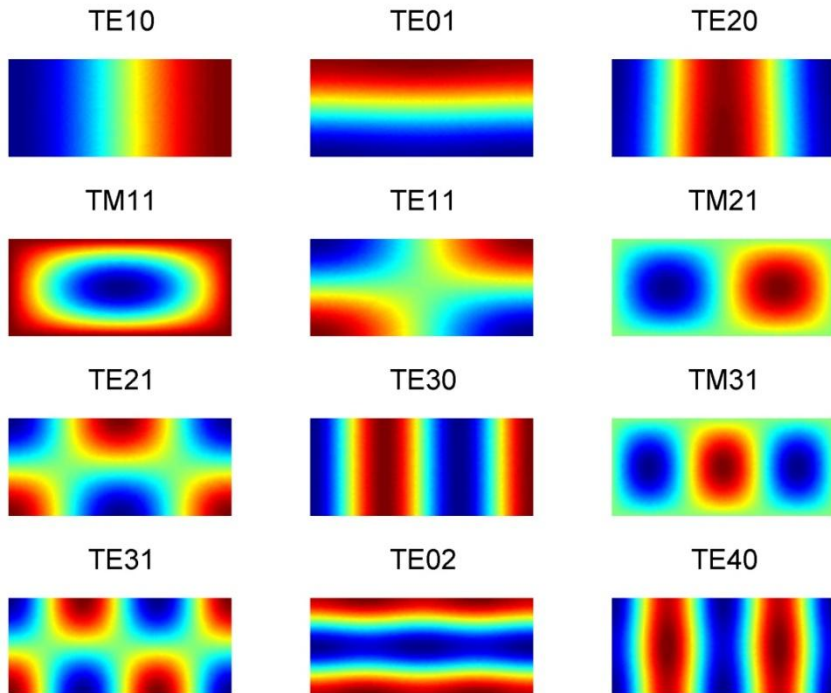
► Similar cu transformata Fourier

$$g(\omega) = \int_{-\infty}^{\infty} f(t) \cdot e^{-j\omega t} dt \quad f(t) = \int_{-\infty}^{\infty} g(\omega) \cdot e^{j\omega t} d\omega$$

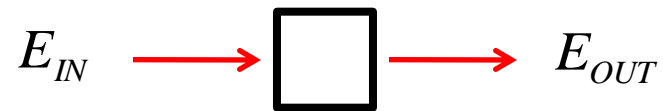
$$E^+, E^- = \sum_1^{\infty} A_i \cdot Mod_i \quad A_i = \langle E, Mod_i \rangle$$

# Modele matematice

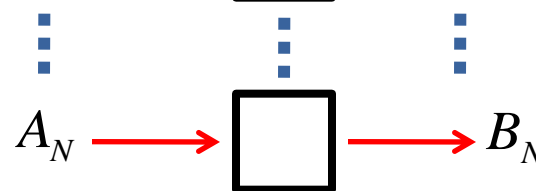
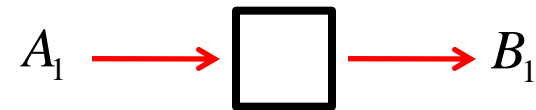
- ▶ cazuri particulare in care exista rezolvare analitica
  - moduri in medii delimitate



$$E = \sum_1^{\infty} A_i \cdot Mod_i \quad A_i = \langle E, Mod_i \rangle$$



$$A_i = \langle E_{IN}, Mod_i \rangle$$



$$E_{OUT} = \sum_1^N B_i \cdot Mod_i$$

# Ghid cilindric dielectric

- ▶ Ecuațiile lui Maxwell in coordonate cilindrice

$$\frac{\partial^2 U}{\partial r^2} + \frac{1}{r} \frac{\partial U}{\partial r} + \frac{1}{r^2} \frac{\partial^2 U}{\partial \phi^2} + \frac{\partial^2 U}{\partial z^2} + n^2 k_o^2 U = 0$$

a – raza miezului  
U – E(r) sau H(r)

$$U(r, \phi, z) = u(r) e^{-jl\phi} e^{-j\beta z}, \quad l = 0, \pm 1, \pm 2, \dots$$

$$\frac{d^2 u}{dr^2} + \frac{1}{r} \frac{du}{dr} + \left( n^2(r) k_o^2 - \beta^2 - \frac{l^2}{r^2} \right) u = 0$$

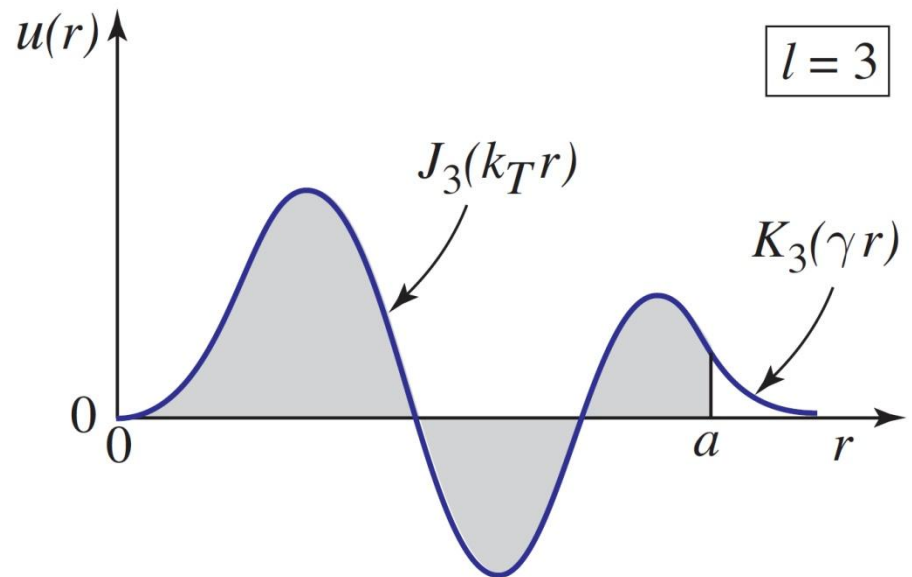
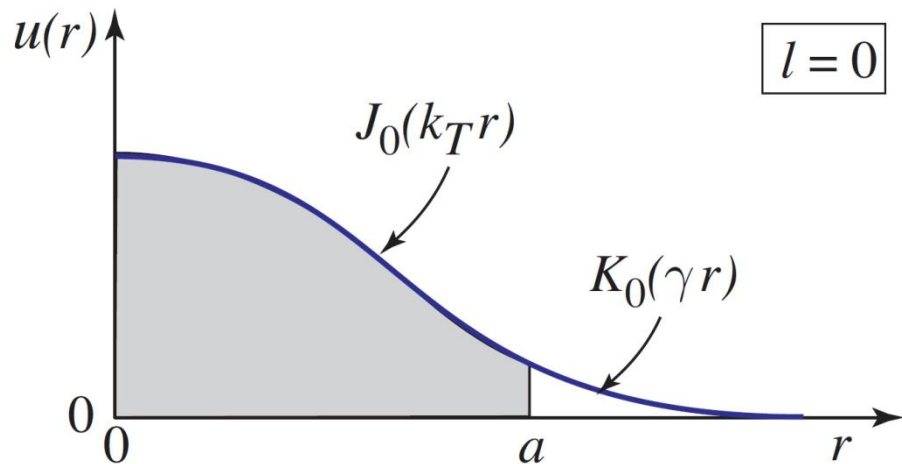
$$\frac{d^2 u}{dr^2} + \frac{1}{r} \frac{du}{dr} + \left( k_T^2 - \frac{l^2}{r^2} \right) u = 0, \quad r < a$$

$$\frac{d^2 u}{dr^2} + \frac{1}{r} \frac{du}{dr} - \left( \gamma^2 + \frac{l^2}{r^2} \right) u = 0, \quad r > a$$

# Ghid cilindric dielectric

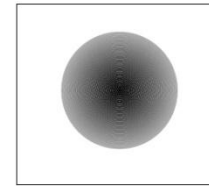
- ▶ soluții proporționale cu funcții Bessel

$$u(r) \propto \begin{cases} J_l(k_T r), & r < a \quad (\text{core}) \\ K_l(\gamma r), & r > a \quad (\text{cladding}) \end{cases}$$

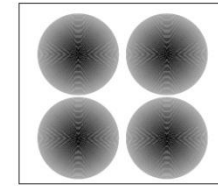


# Moduri in fibra

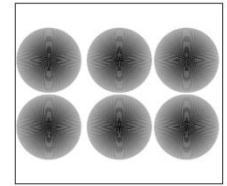
- ▶ Moduri in ghid rectangular



TEM<sub>00</sub>

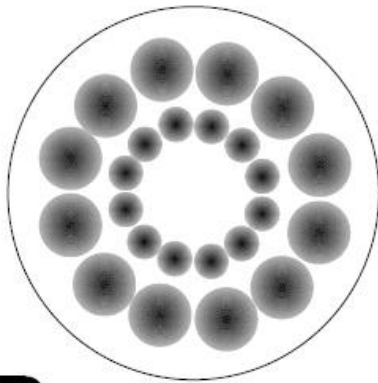


TEM<sub>11</sub>

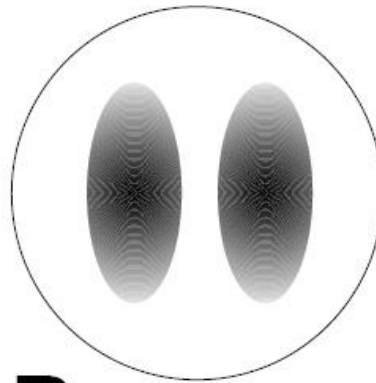


TEM<sub>21</sub>

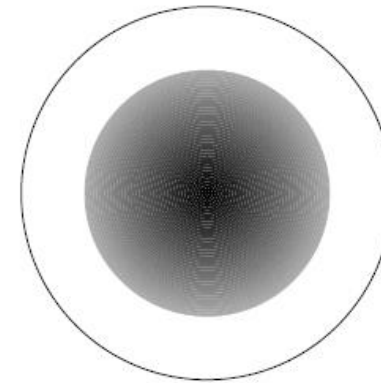
- ▶ Moduri linear polarizate in fibra



LP<sub>62</sub>

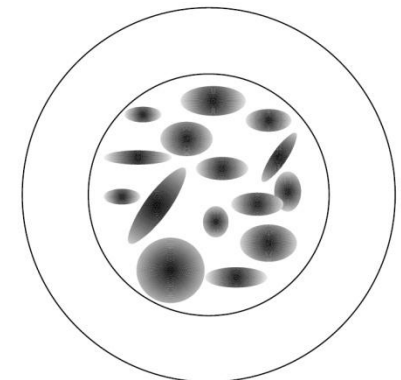


LP<sub>11</sub>



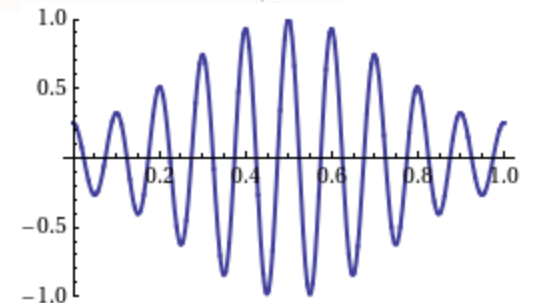
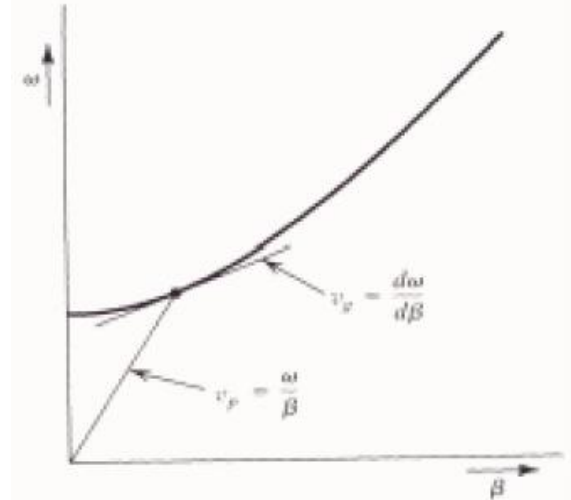
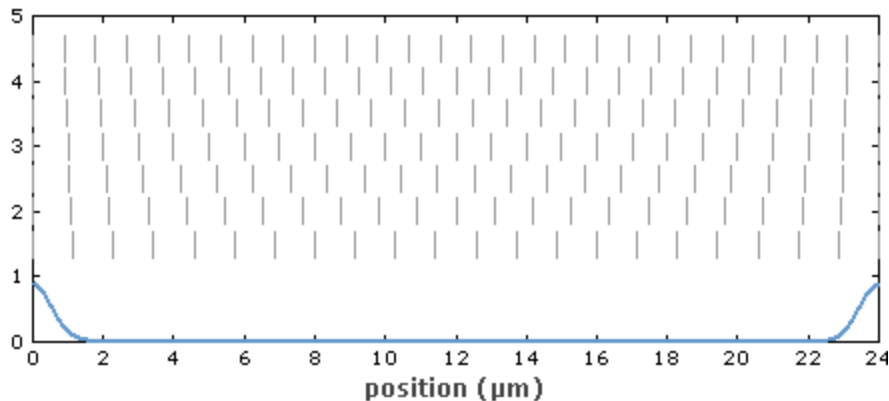
LP<sub>01</sub>

“Sparkle” pattern



# Viteze de grup si faza

- ▶ Viteza de faza – viteza virtuala cu care circula punctul cu o anumita faza
- ▶ Viteza de grup – viteza cu care circula informatia (energia) – in medii cu dispersie normala



# Dispersia

- ▶ In medii dispersive  $\beta = \beta(\omega)$ ,  $n = n(\omega)$

$$\frac{d\beta}{d\omega} = \frac{d}{d\omega} \left( \frac{\omega \cdot n}{c} \right) = \frac{1}{c} \left( n + \omega \frac{dn}{d\omega} \right)$$

$$\frac{d\beta}{d\omega} = -\frac{\lambda}{\omega} \cdot \frac{d\beta}{d\lambda} = \frac{1}{c} \left( n - \lambda \frac{dn}{d\lambda} \right) = \tau \quad (s/m)$$

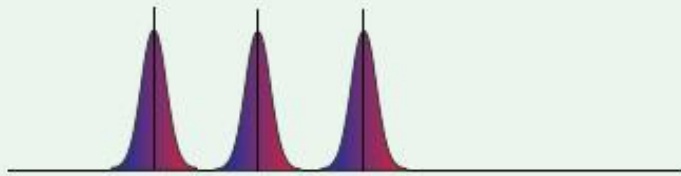
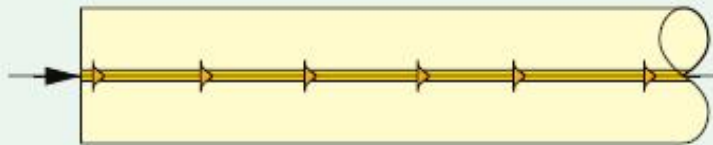
$$D = \frac{d\tau}{d\lambda} = \frac{1}{c} \left( \frac{dn}{d\lambda} - \lambda \frac{d^2n}{d\lambda^2} - \frac{dn}{d\lambda} \right) = -\frac{\lambda}{c} \frac{d^2n}{d\lambda^2} \quad (s/m^2)$$

- ▶ Dispersia se exprima de obicei in **ps/nm/km** si permite aflarea intarzierilor aparute intre "moduri" (latirea impulsurilor) pentru o anumita latime spectrala si o anumita distanta parcursa

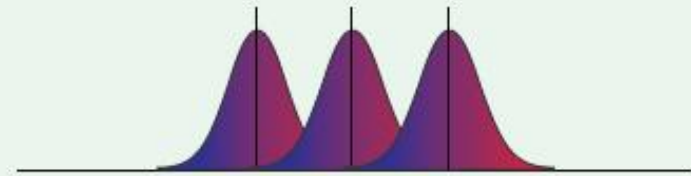
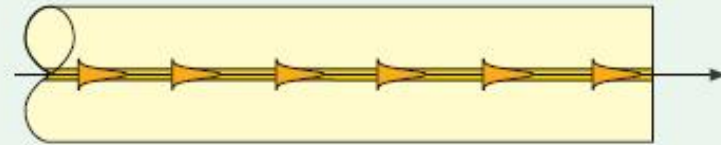
$$\Delta\tau = D \cdot \Delta\lambda \cdot L$$

# Dispersie

> 50 km Single-mode step index  
< 10 km Multimode graded index  
< 1 km Multimode step index



Transmission:  
Well-defined pulses but not absolutely monochromatic.  
Typical spectral width < 0.8 nm



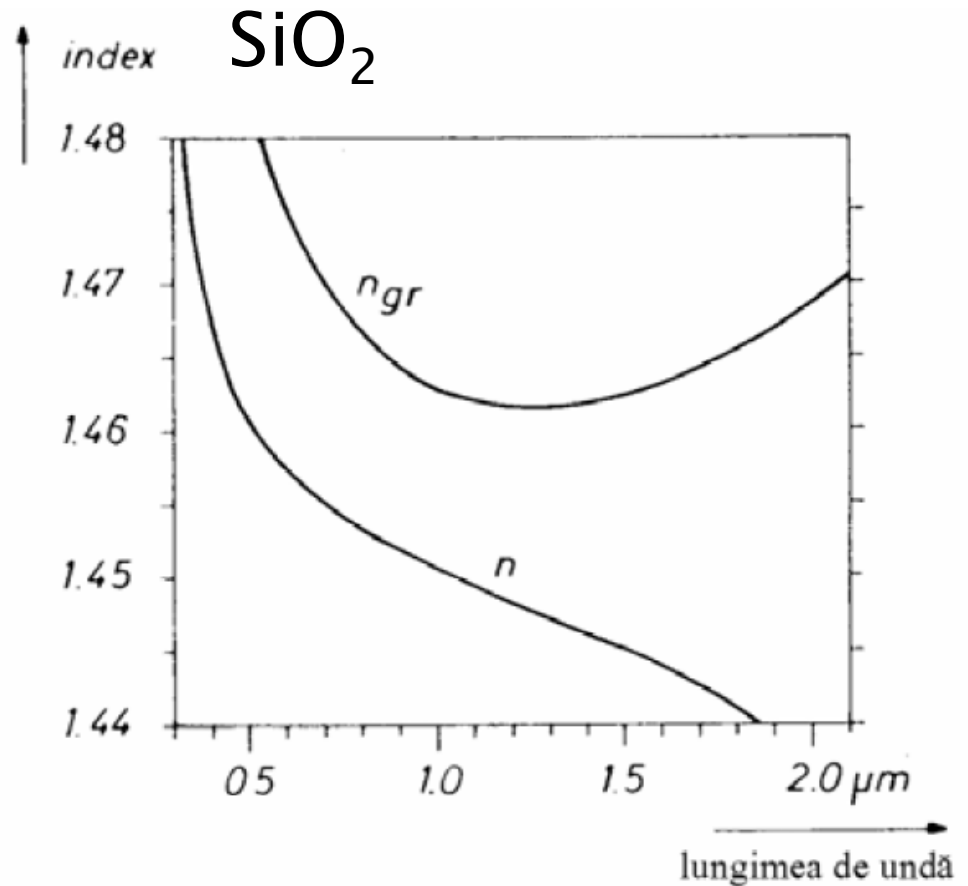
Reception:  
Pulse broadening caused by the laser's spectral width and the difference between the refractive indices of the red and blue ends of the light pulse.



# Dispersie normala

$$n_{gr} = n - \lambda \frac{dn}{d\lambda}$$

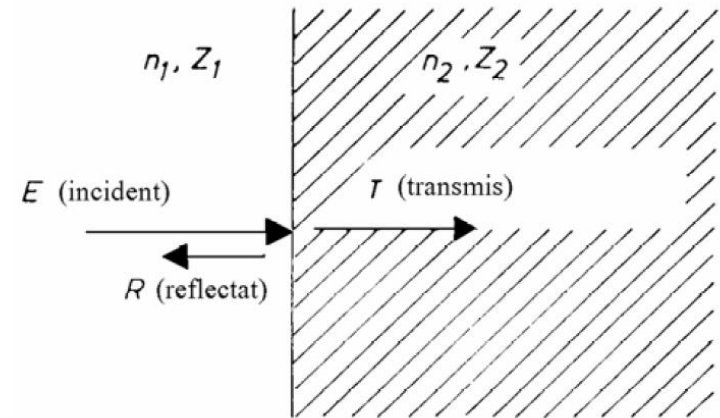
$$D = \frac{d\tau}{d\lambda} = \frac{1}{c} \cdot \frac{dn_{gr}}{d\lambda}$$



# Transmisia puterii între medii

- ▶ incidenta normala
- ▶ reflexia in amplitudine

$$Z = \frac{Z_0}{n} \quad \Gamma = \frac{Z_2 - Z_1}{Z_2 + Z_1} = \frac{n_1 - n_2}{n_1 + n_2}$$



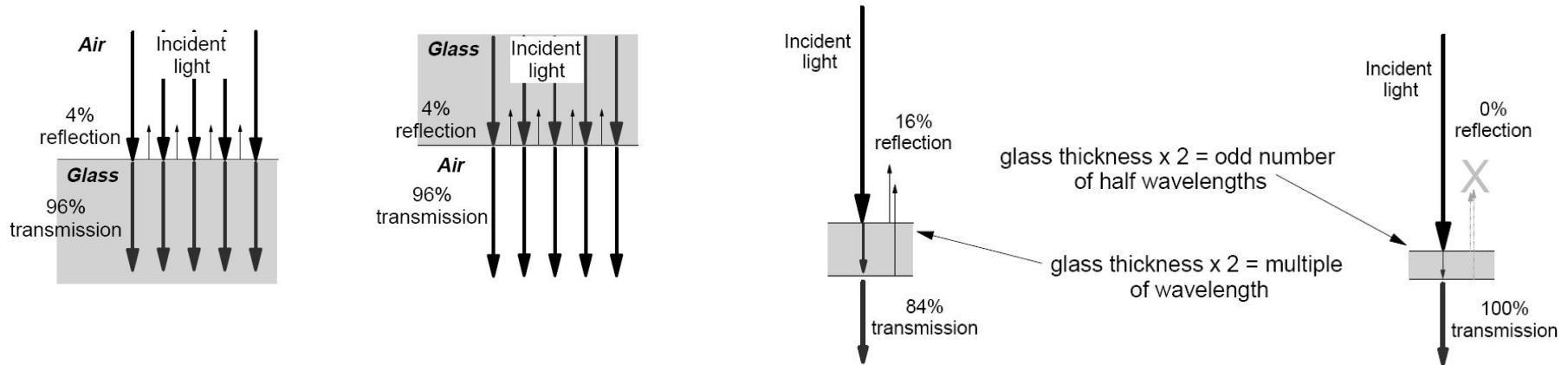
- ▶ densitatea de putere proportionala cu patratul amplitudinii câmpului

$$r = \left( \frac{n_1 - n_2}{n_1 + n_2} \right)^2 \quad t = \left( \frac{2n_1}{n_1 + n_2} \right)^2$$

- ▶ interfata aer–sticla ( $n_1 = 1$ ,  $n_2 = 1.5$ )

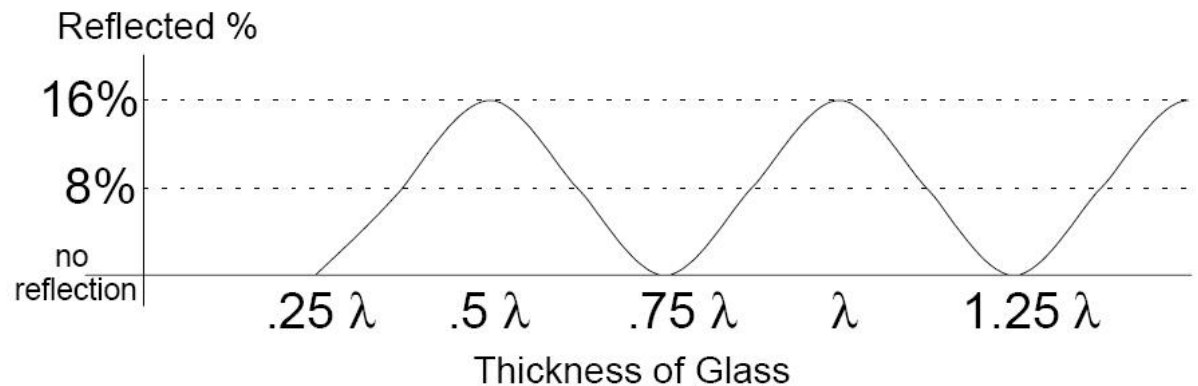
$$r = 0.04 = 4\%$$

# Transmisia printr-o lamela



$$\Gamma = \frac{1.5 - 1}{1.5 + 1} = 0.2; \quad r = \Gamma^2 = 0.04 = 4\% \quad \Gamma_{\max} = 0.2 + 0.2; \quad r_{\max} = \Gamma_{\max}^2 = 0.16 = 16\%$$

- ▶ apare interferența între diversele unde reflectate
- ▶ se adună câmpurile nu puterile
- ▶ lamele antireflexive

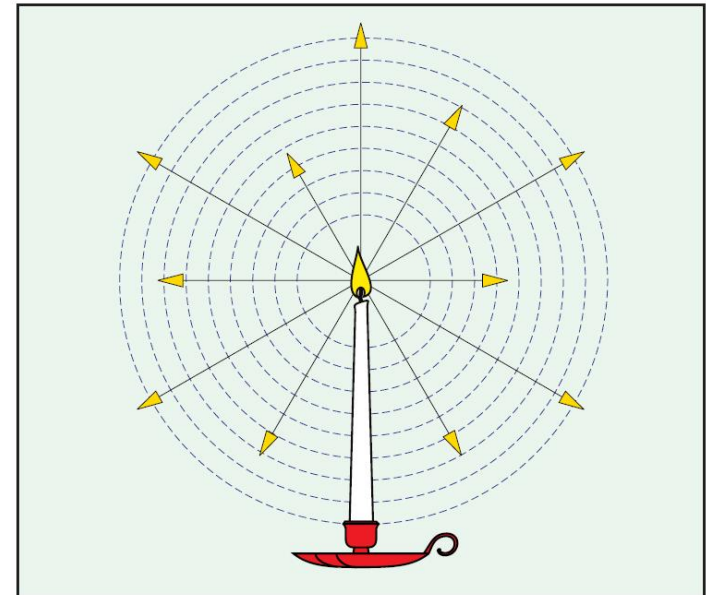
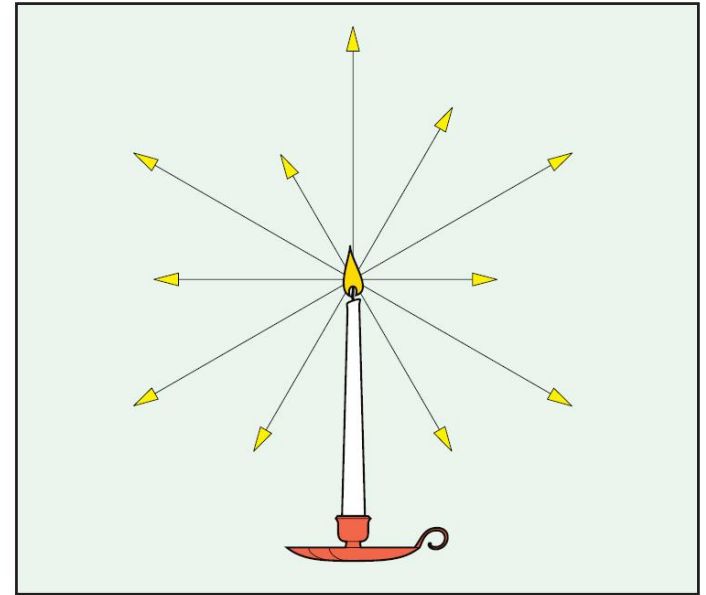


# Optică geometrică

(tot) Capitolul 2

# Raze de lumina

- ▶ Lumina este constituita din raze care se propaga in linie dreapta in medii omogene
- ▶ Sursa omnidirecțională: emite similar in toate direcțiile
- ▶ Densitatea de energie luminoasa descrește invers proporțional cu pătratul distantei fata de sursa (energia se împarte uniform pe suprafața întregii sfere)



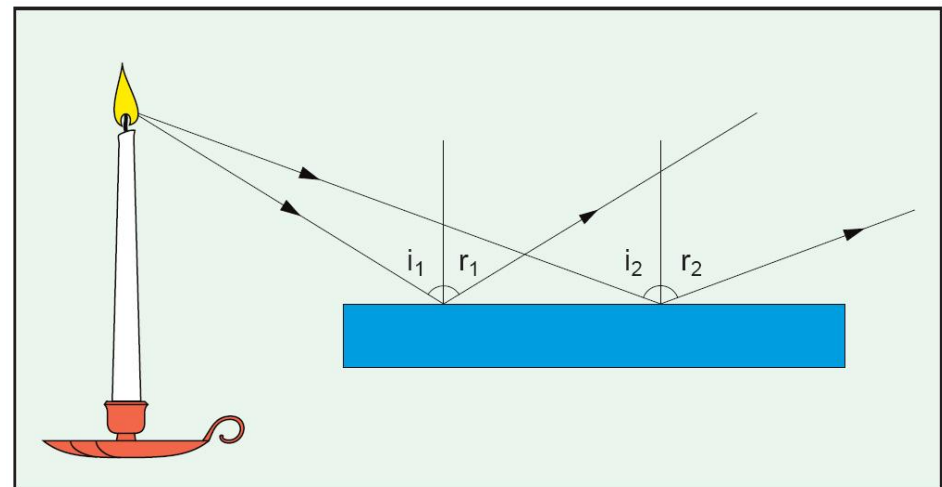
$$P = \frac{P_0}{r^2}$$

# Reflexia luminii

- ▶ la suprafata de separatie dintre doua medii, (o parte din) lumina se intoarce in mediul de incidenta
- ▶ unghiul dintre raza incidenta si normala ( $\phi_i$ ) este egal cu unghiul dintre raza reflectata si normala ( $\phi_r$ )

## ▶ Legea reflexiei

$$\phi_i = \phi_r$$



# Refractia luminii

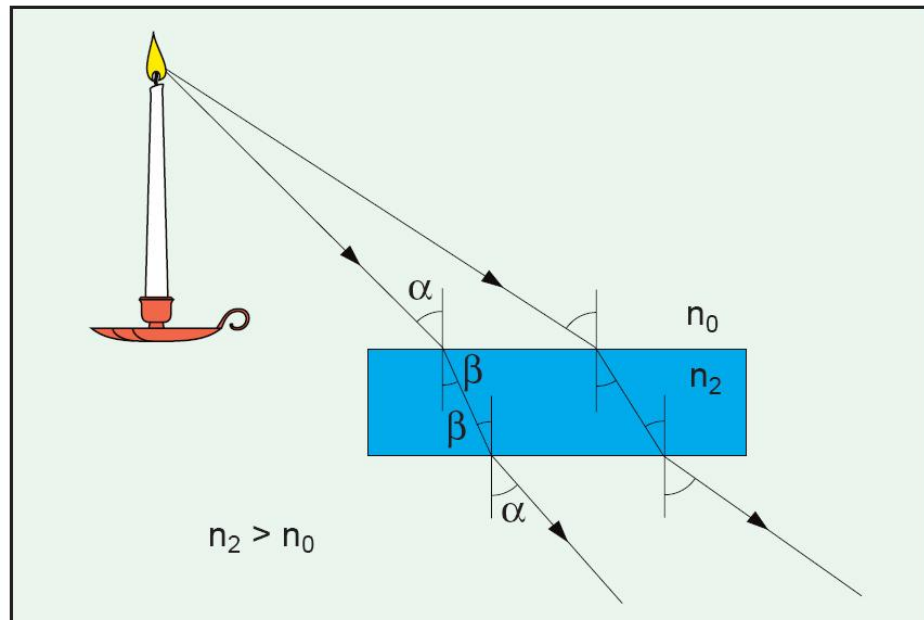
- ▶ la suprafața de separație dintre doua medii, (o parte din) lumina se (poate) propaga in mediul de transmisie sub un unghi diferit de unghiul incident
- ▶ la trecerea in medii mai “dense” (optic) lumina se apropie de normala
- ▶ la trecerea in medii mai “puțin dense” (optic) lumina se depărtează de normala

## ▶ Legea lui Snell (a refracției)

$$n_1 \cdot \sin \phi_i = n_2 \cdot \sin \phi_R$$

$\phi_i$  - unghi incident (in  $n_1$ )

$\phi_R$  - unghi de refracție (in  $n_2$ )



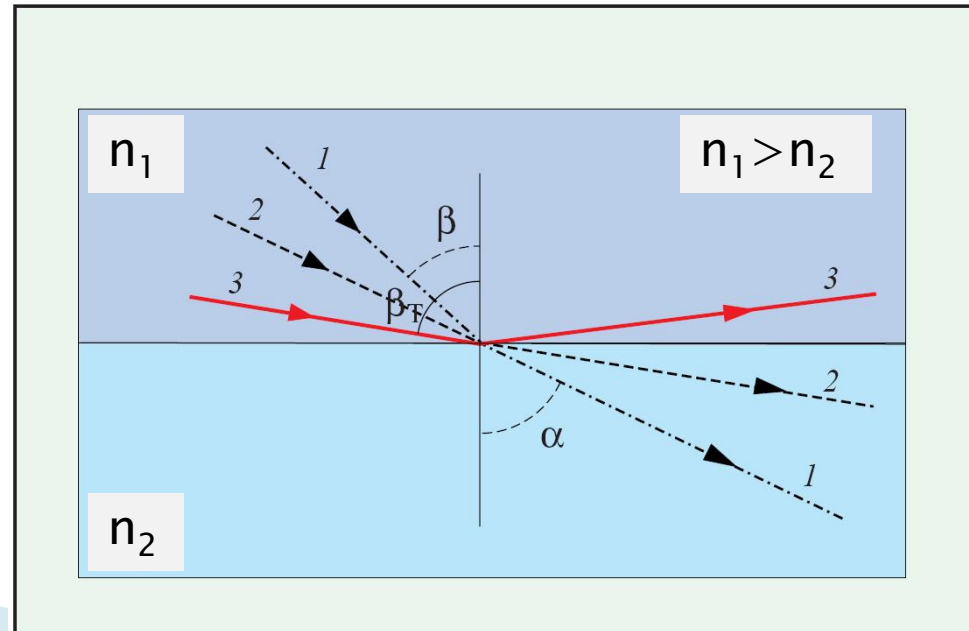
# Reflexia totala

- ▶ Apare **numai când** lumina se propaga dintr-un mediu mai dens optic într-un mediu mai puțin dens
- ▶ La intersecția luminii cu suprafața de separație a doua medii se întâlnesc în general raze reflectate **și** raze refractate
- ▶ Pentru un unghi de incidență numit **unghi critic**, raza refractată se obține în lungul suprafeței de separație
- ▶ Pentru orice unghi mai mare decât unghiul critic există numai raza reflectată

$$n_1 > n_2; \quad \phi_R = 90^\circ$$

$$n_1 \cdot \sin \phi_C = n_2$$

$$\phi_C = \arcsin\left(\frac{n_2}{n_1}\right)$$



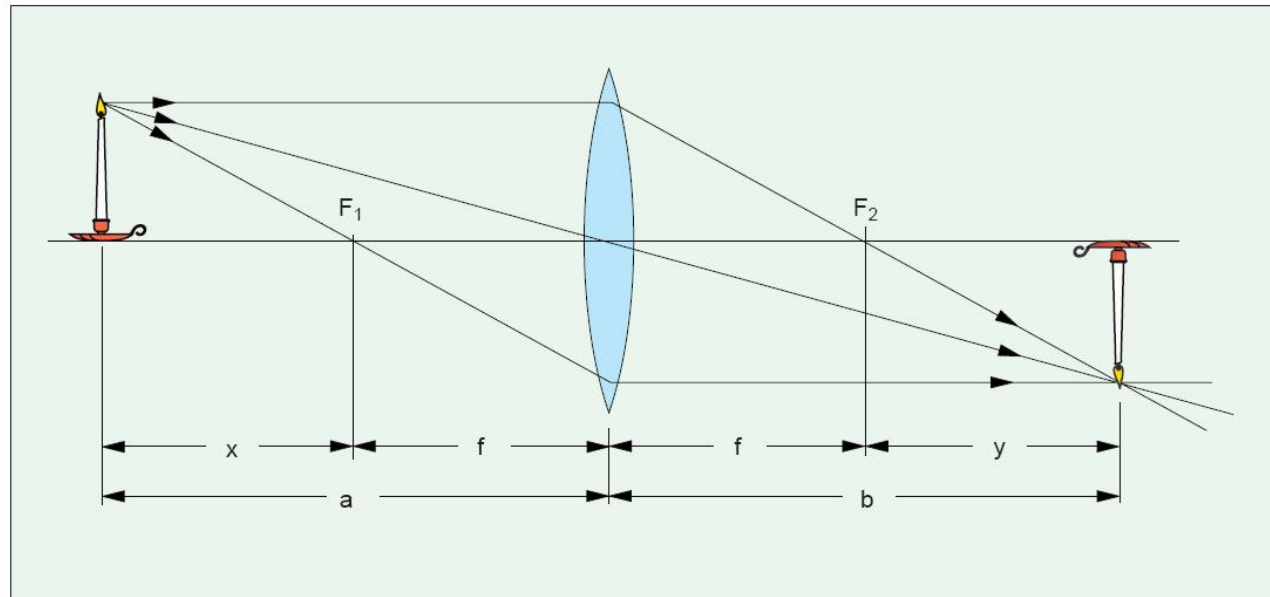


# Lentile

- ▶ Razele de lumina paralele sunt concentrate intr-un punct numit focar, aflat la **distanța focala** de planul lentilei
- ▶ O sursa omnidirectională poziționată în focar va permite obținerea unui fascicul paralel

$$\frac{1}{a} + \frac{1}{b} = \frac{1}{f}$$

$$x \cdot y = f^2$$

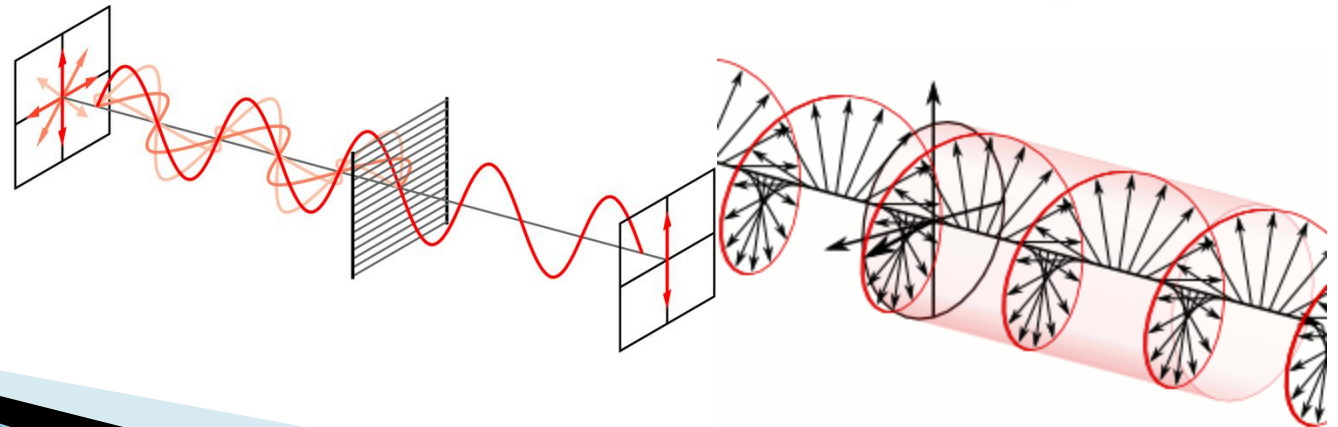
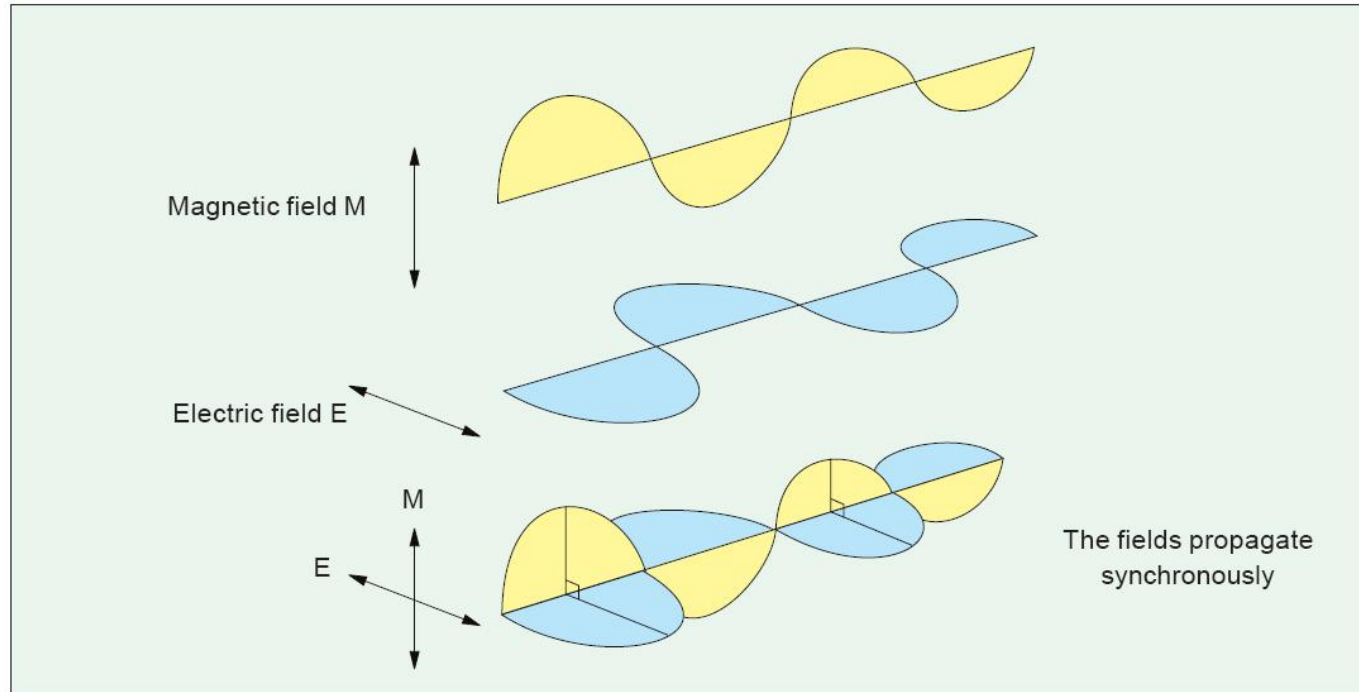


# Lumina ca undă electromagnetică

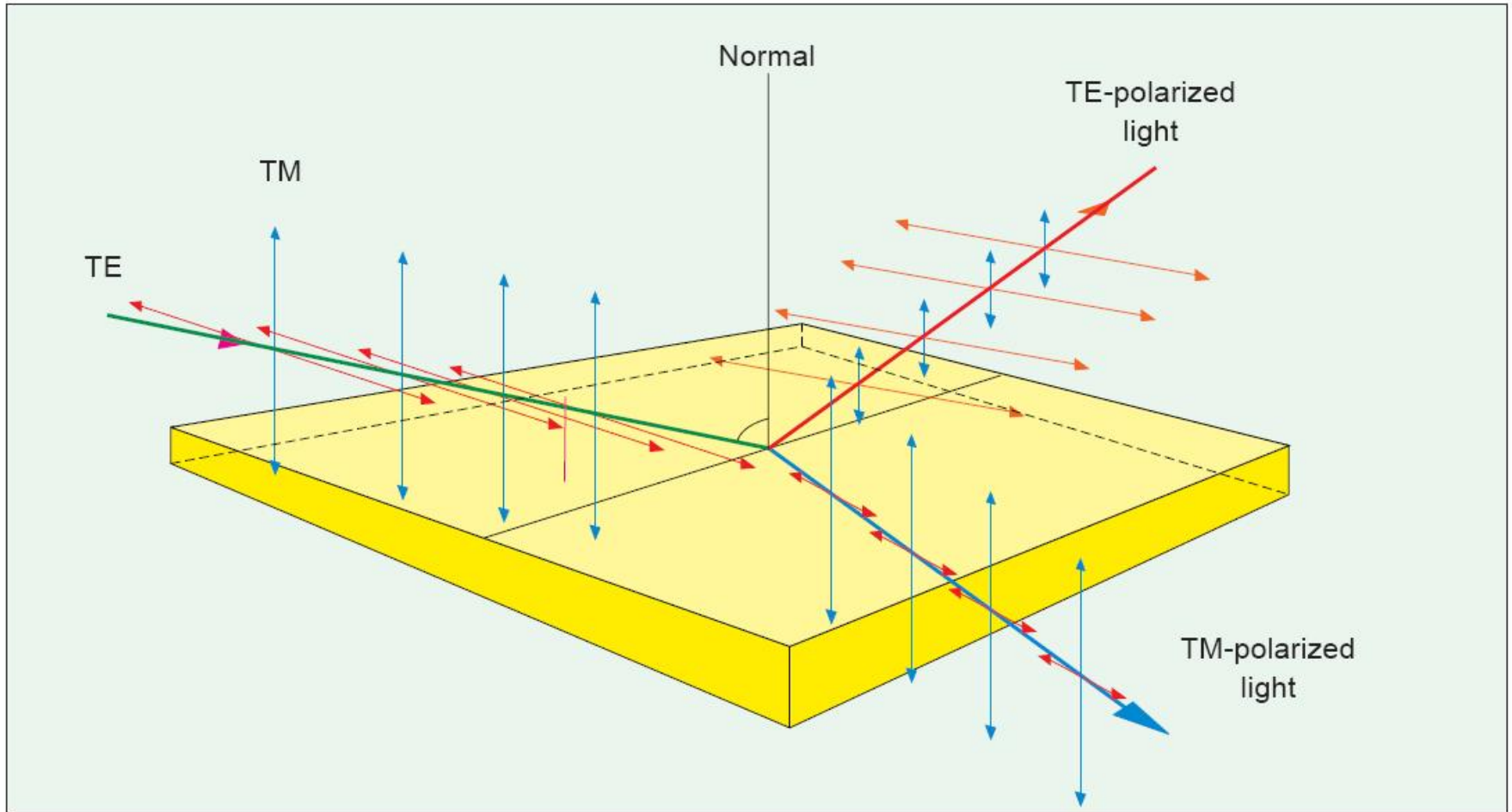
Capitolul 2

**Continuare**

# Polarizarea luminii



# Polarizarea luminii



# Polarizarea luminii

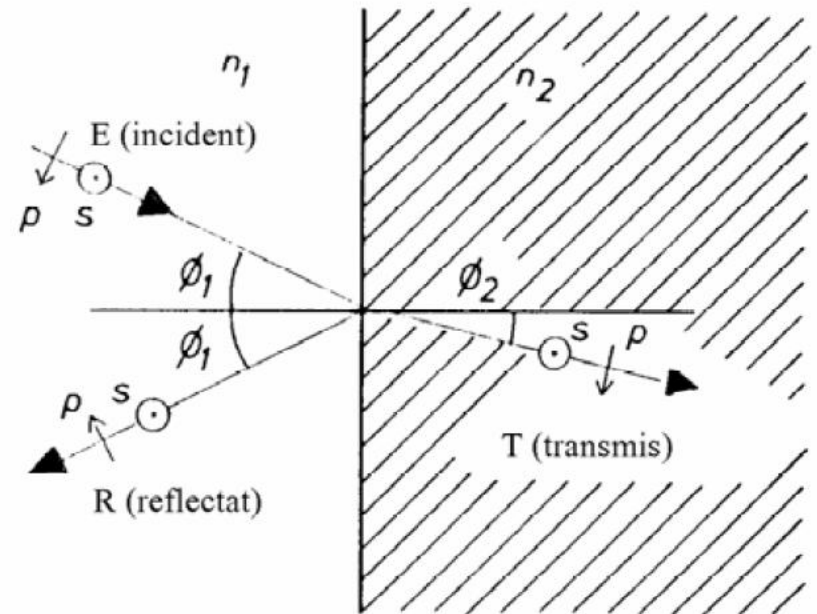
- ▶ incidenta oblica
- ▶ reflexiile in amplitudine a campului:

$$r_s = -\frac{\sin(\phi_1 - \phi_2)}{\sin(\phi_1 + \phi_2)}$$

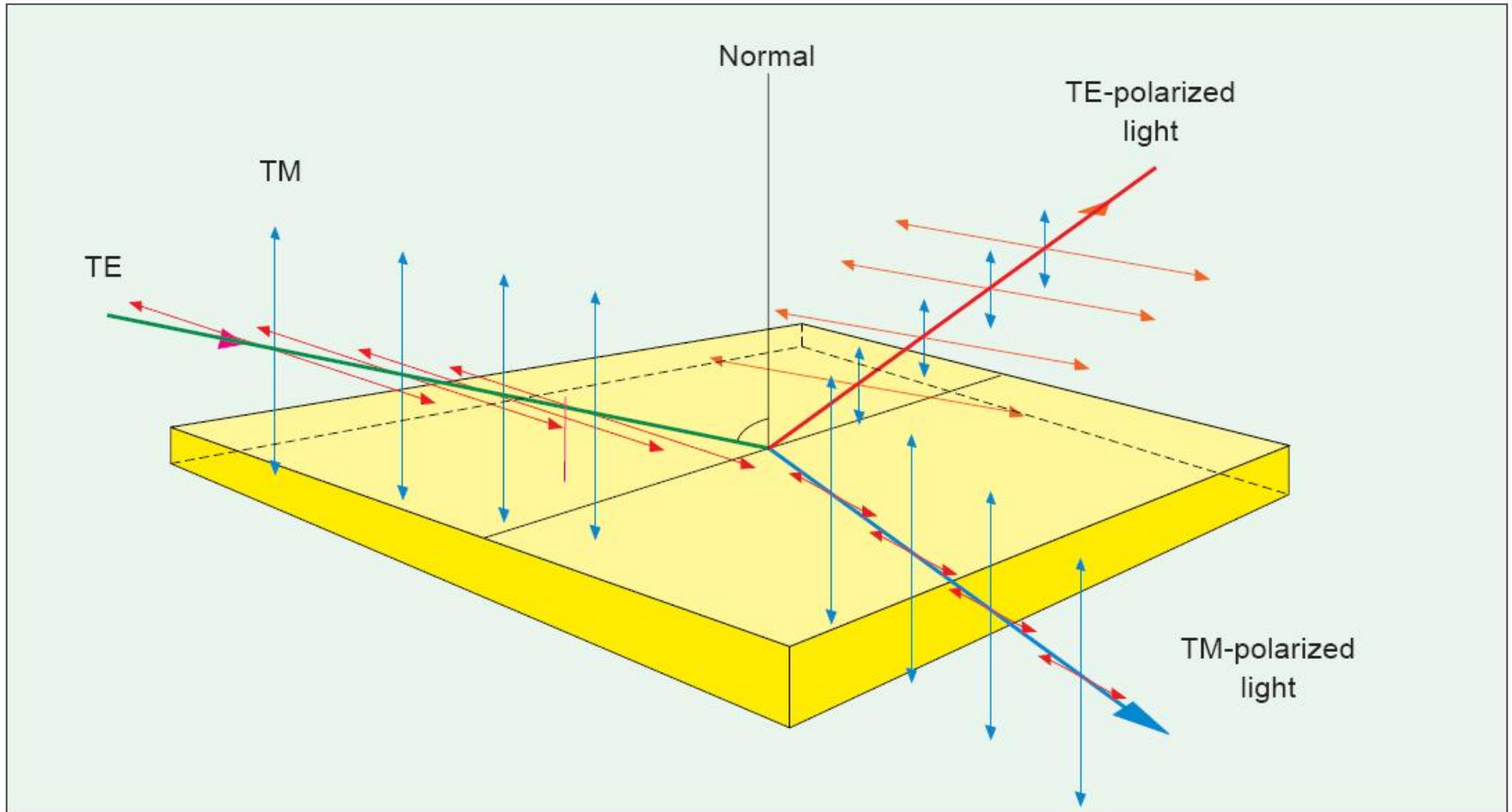
$$r_p = \frac{\tan(\phi_1 - \phi_2)}{\tan(\phi_1 + \phi_2)}$$

$$t_s = \frac{2 \sin \phi_2 \cos \phi_1}{\sin(\phi_1 + \phi_2)}$$

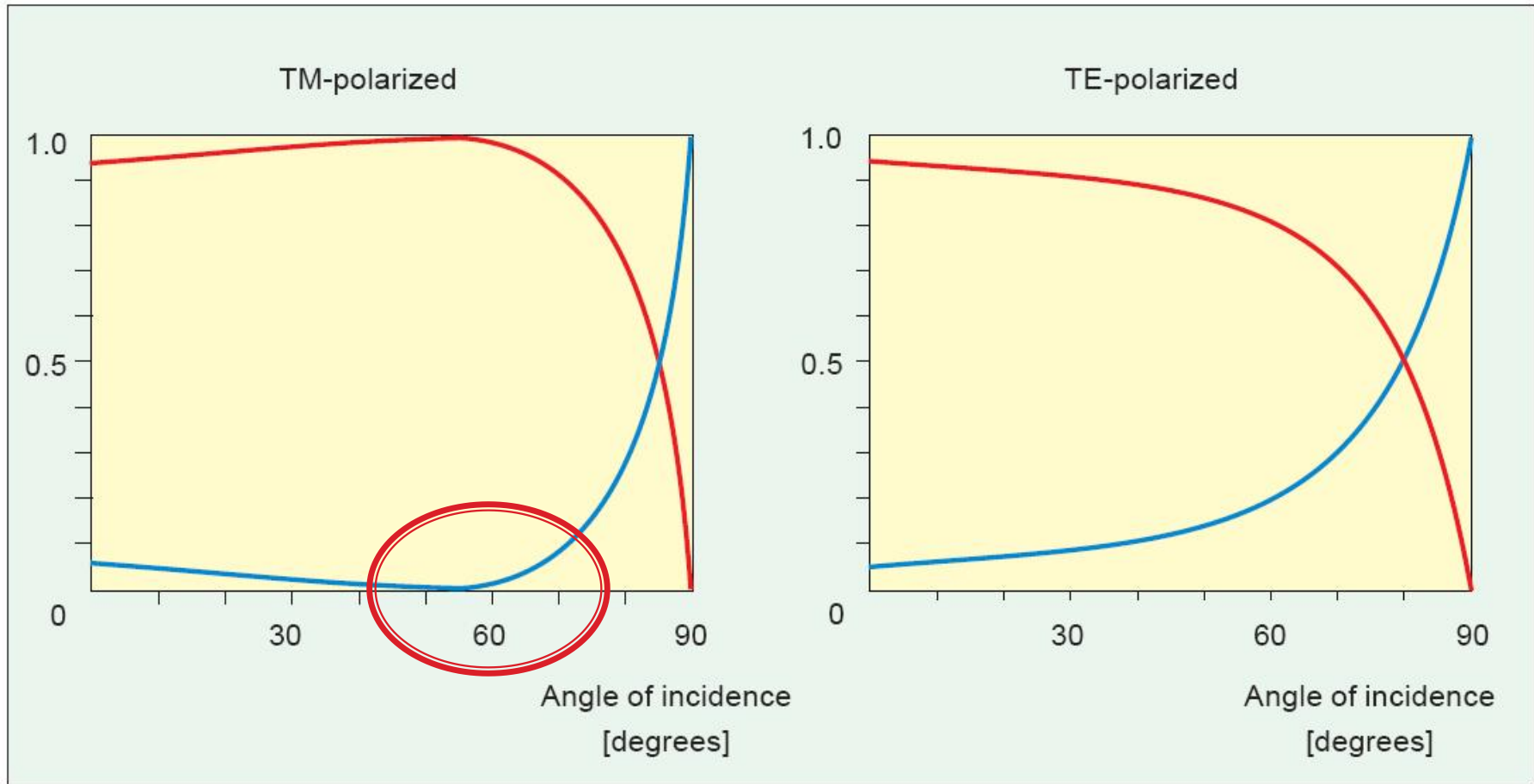
$$t_p = \frac{2 \sin \phi_2 \cos \phi_1}{\sin(\phi_1 + \phi_2) \cos(\phi_1 - \phi_2)}$$



# Polarizarea luminii



# Polarizarea luminii





# Unghi Brewster

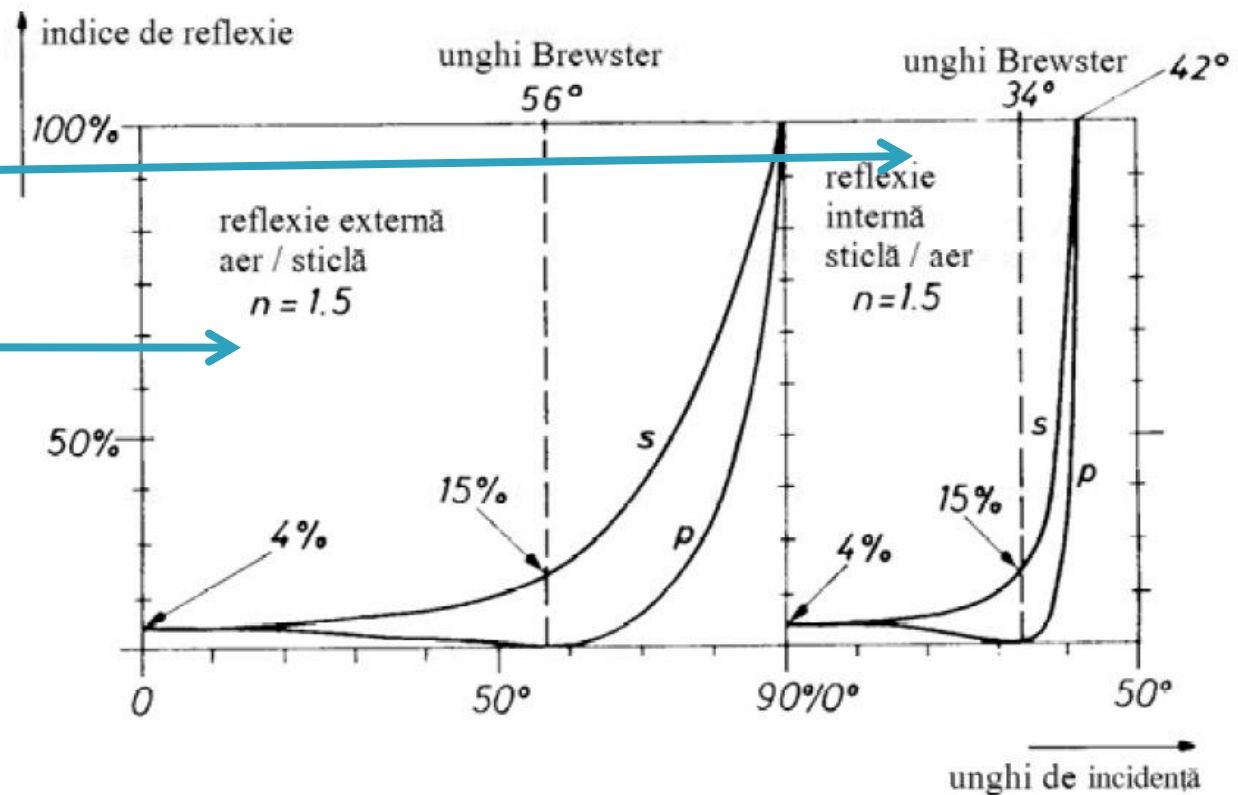
$$r_p = 0 \Rightarrow \tan(\phi_1 + \phi_2) \rightarrow \infty \Rightarrow \phi_1 + \phi_2 = \frac{\pi}{2}$$

$$n_1 \cdot \sin \phi_1 = n_2 \cdot \sin \phi_2 = n_2 \cdot \cos \phi_1$$

$$\phi_B = \arctan\left(\frac{n_2}{n_1}\right)$$

$$\phi_B = 34^\circ$$

$$\phi_B = 56^\circ$$



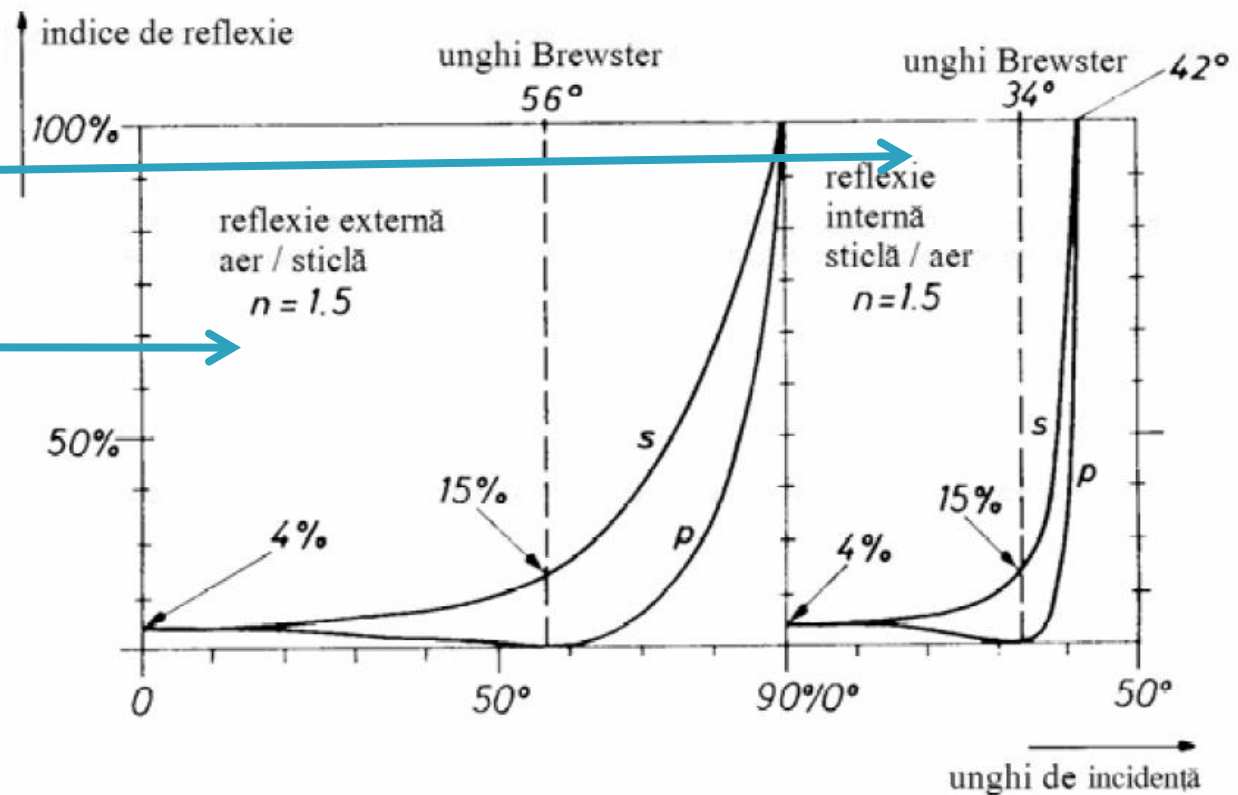
# Unghi Brewster

- ▶ transmisia totala a polarizarii p
- ▶ lumina reflectata este total polarizata (s)

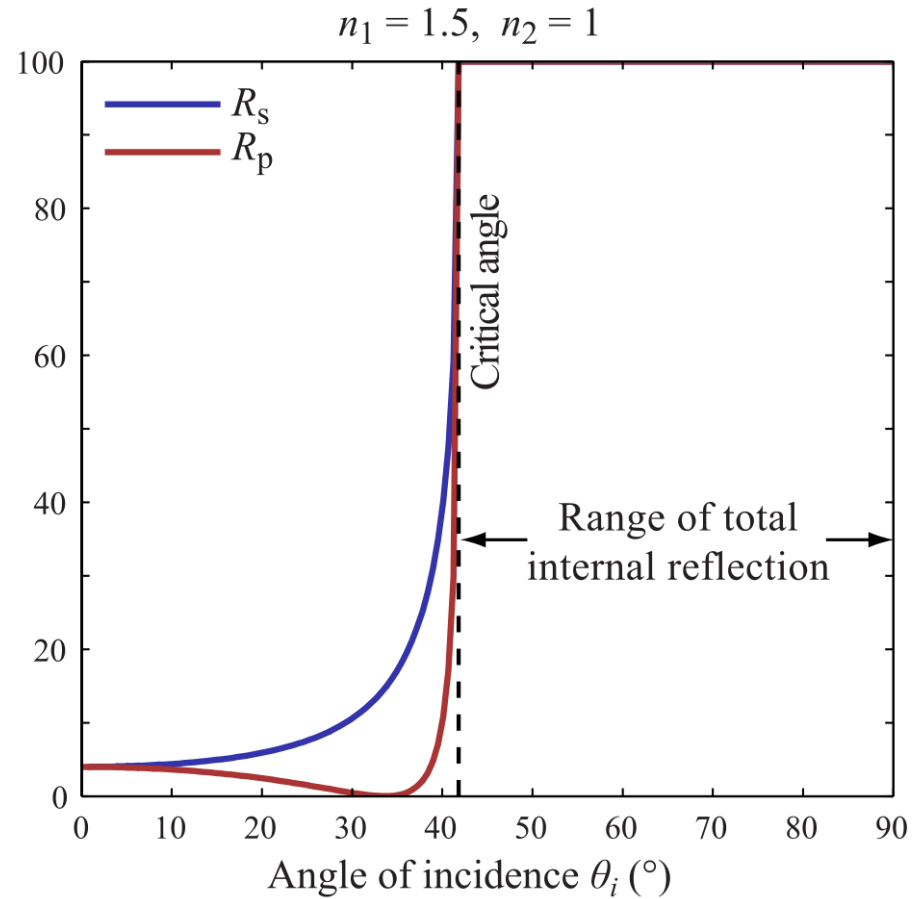
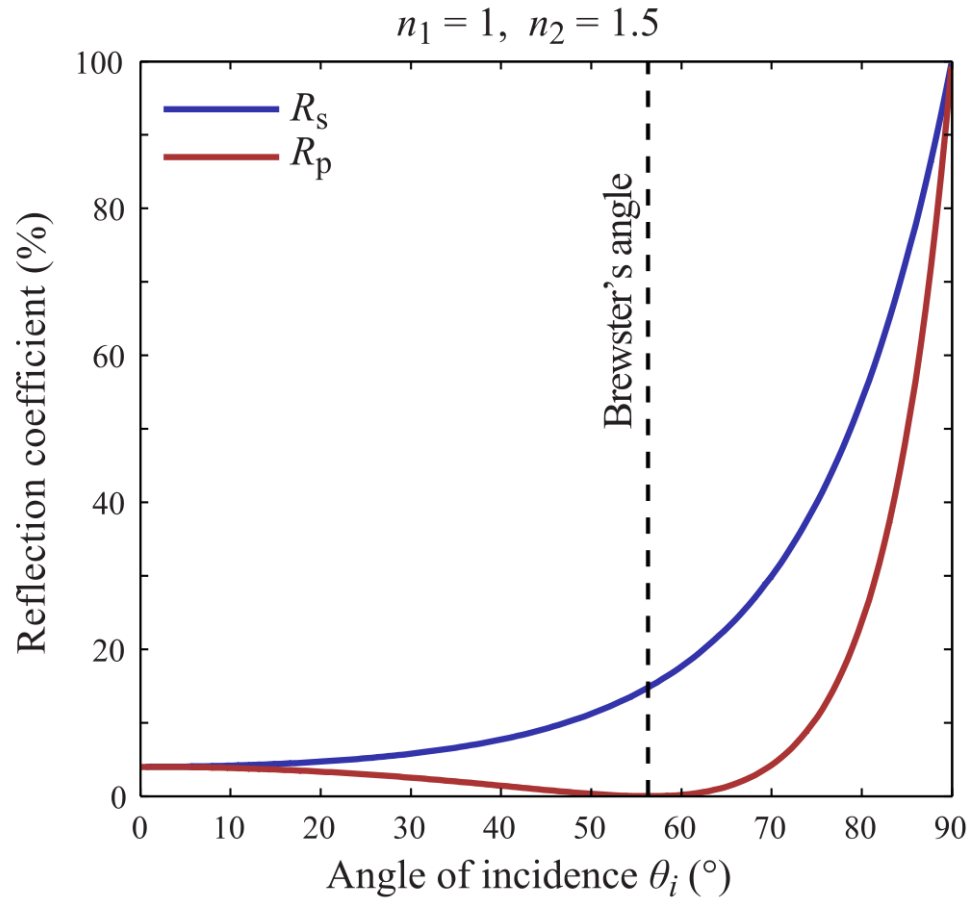
$$\phi_B = \arctan\left(\frac{n_2}{n_1}\right)$$

$$\phi_B = 34^\circ$$

$$\phi_B = 56^\circ$$



# Unghi Brewster



# Contact

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- ▶ [rdamian@etti.tuiasi.ro](mailto:rdamian@etti.tuiasi.ro)